CRWR Online Report 05-14

GeoSpatial HSPF Model of the Sandies and Elm Watershed, Texas

by

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May 2006

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Acknowledgements

To my husband, Alex, for his love and support,

To my children, Gabriel and Holly, for their love and laughter,

To my parents, Henry and Marjorie Luttrell, for their love and support,

To Dr. David Maidment, who taught me, guided me, and helped me to see the vision beyond the work,

To Dr. Lynn Katz, who shared her love of water chemistry and water quality modeling,

To Nate Johnson, whose research laid the foundation for my own,

To Carrie Gibson and Becky Teasley and all the students and faculty at CRWR and EWRE for their friendship and support,

I give my heartfelt appreciation and thanks.

May 2006

Abstract

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Sandies and Elm Watershed, Texas

Jessica Luttrell Watts, M.S.E.

The University of Texas at Austin, 2006

Co-Supervisors: David Maidment and Lynn Katz

The Sandies and Elm Creeks were placed on EPA's 303(d) list in 2000 due to depressed dissolved oxygen and elevated bacteria levels. Given the rural, agricultural nature of the watershed, a Total Mass Daily Load (TMDL) study was initiated to determine the source or sources of the non-point source pollution. A model needed to be developed that simulated the agricultural runoff from the watershed. The simulation model, Hydrologic Simulation Program – FORTRAN (HSPF) was chosen. A typical HSPF model was conceived, but during the course of the study circumstances forced the model to develop in an atypical way. The classic source of precipitation forcing data, the National Climatic Data Center, lacked point precipitation stations with data during the calibration timeframe; therefore alternate data sources were reviewed and NEXRAD data was chosen as the alternate data source. But, the use of NEXRAD data required that the model be distributed to a greater degree than a classic HSPF model. This delineation pushed the HSPF code to the edge of its design and encouraged examination of the weaknesses of both HSPF and hydrologic modeling in general.

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Chapter 1 Introduction

1.1 INTRODUCTION

The Sandies and Elm Creeks were placed on EPA's 303(d) list in 2000 due to depressed dissolved oxygen and elevated bacteria levels. Given the rural, agricultural nature of the watershed, a Total Mass Daily Load (TMDL) study was initiated to determine the source or sources of the non-point source pollution. A model needed to be developed that simulated the agricultural runoff from the watershed. The computer model, Hydrologic Simulation Program – FORTRAN (HSPF) was chosen for two reasons. First, it is recommended by the EPA for use in non-point source .pollution watershed modeling and second, the model has the ability to simulate continuously on a given time step.

A typical HSPF model was conceived, but during the course of the study circumstances encouraged the model to develop in an atypical way. The classic source of precipitation forcing data, the National Climatic Data Center, lacked point precipitation stations with data during the calibration timeframe; therefore alternate data sources were reviewed and NEXRAD data was chosen as the alternate data source. But, the use of NEXRAD data required that the model be distributed to a greater degree than a classic HSPF model. This delineation pushed the HSPF code to the edge of its design and supported examination of the weaknesses of both HSPF and hydrologic modeling in general.

1.2 PURPOSE AND SCOPE

The purpose of this study is to examine various aspects of the application of the HSPF model to the Sandies and Elm watershed, Texas. Initially prompted by the need to develop a continuous hydrologic simulation model for a TMDL study in this watershed, the scope was later broadened to include an examination of the effect of various sources of rainfall input on the HSPF simulated flow.

A hydrologic and water quality model for the Sandies and Elm watershed was developed using the Hydrologic Simulation Program – FORTRAN (HSPF) simulation model. The model incorporates basin specific information, in a timeseries format, which includes measured stream flow, as well as precipitation and evaporation forcing data. Additionally, the model also includes characteristics of the topography, soils, land use / land cover, and vegetation. The model was calibrated with measured stream flow data and where available and to the degree possible, the model parameters were physically based.

1.3 DOCUMENT OUTLINE

This thesis is divided into seven chapters. The first is the introduction which gives an overview of the thesis as well as the objective and scope of the study undertaken. Chapter two presents an overview of the Sandies and Elm watershed as well as a brief explanation of the Total Mass Daily Load (TMDL) study process and a water quality history of the watershed. Chapter three provides an overview of hydrologic modeling in general and HSPF specifically. It describes the model structure as well as the history of the model's development. A discussion of different aspects in the model development is included in Chapter four through six. Chapter four describes the motivation behind the atypical development of the HSPF model and includes a discussion of differences between NEXRAD and NCDC gage interpolation methods. It lays out an explanation of the different precipitation sources and compares select storms for evaluation of NEXRAD and NCDC data. Chapter five describes the process and data used in the HSPF model development. It begins with a very brief overview of the ArcGIS to HSPF preprocessing methodology used in initially creating the HSPF model, and then a discussion of data collection methods is presented. Definitions of those HSPF features that could be defined through known information of the physical watershed are also provided. Chapter six continues with the model development, but concentrates on the calibration and parameterization of watershed features that cannot be defined through known physical characteristics. Chapter six covers both the standard HSPF calibration methods as well as those specific to this study. The chapter concludes with the results of the model. Chapter seven contains the conclusions of the study and somewhat more importantly the recommendations for future development in water quality modeling. It describes a vision for the future of hydrological water quality modeling.

Chapter 2 Background

2.1 SANDIES AND ELM WATERSHED

The Sandies and Elm watershed is part of the Guadalupe River Basin in South Central Texas. The watershed is located 34 miles East-Southeast of San Antonio, and is situated between the Medina and Guadalupe Rivers. The watershed covers an area of 712 square miles and extends into portions of five counties: DeWitt, Gonzales, Guadalupe, Karnes, and Wilson. Figure 2.1 identifies the geographic location of the watershed study area. The watershed terrain varies from level to rolling land, and elevation ranges from 130 to 745 feet. There is only one major town in the watershed, Nixon, which has a population of 2,186 people. (US Census Bureau, 2000)

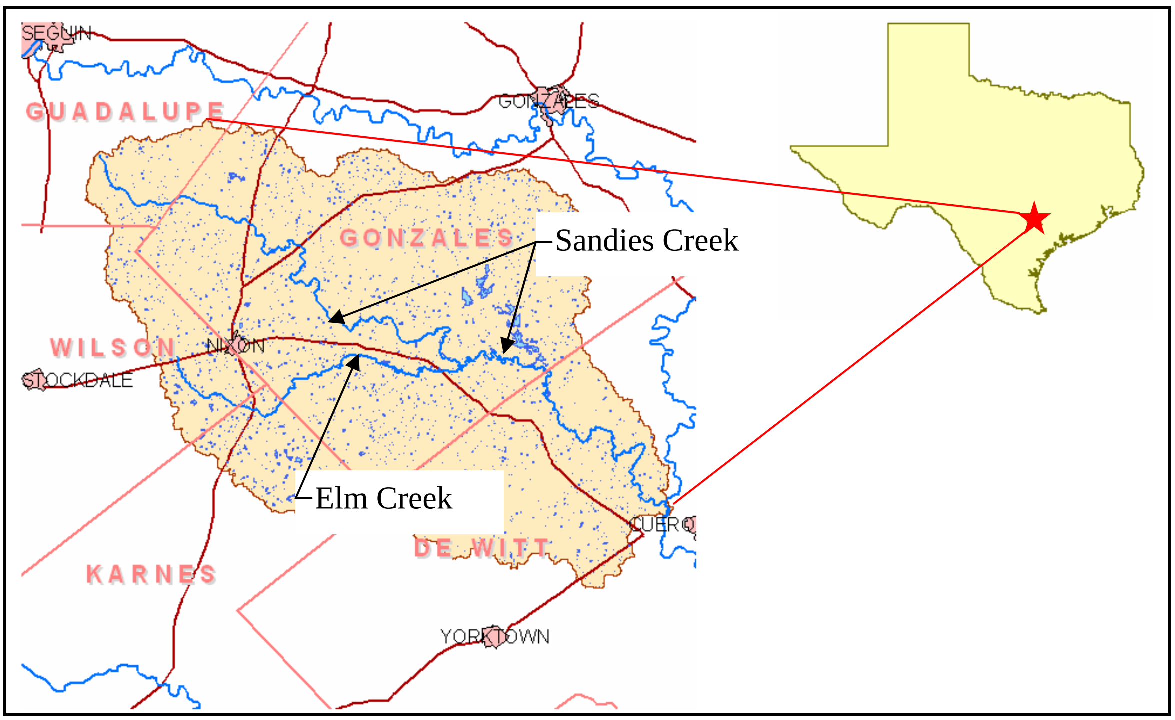

Figure 2.1: Sandies and Elm Watershed Study Area

Seventy-five (75) types of soils overlying 19 different geologic formations have been classified in Gonzales County, in which most of the Sandies and Elm watershed is contained. This area has the most diversified soil variety of any county in the state. Dark Red sandstone is abundant in the northeast part of the watershed. Sandy loam soil is plentiful in the northwest portion of the watershed. The soils contained in Wilson and Karnes Counties have light to dark, loamy surfaces over reddish, clayey subsoils with limestone within forty inches of the surface, and gray to black, cracking. The Salt Creek Flats can be found in the southern portion of Gonzales County. The Flats furnished the early settlers with enough salt to satisfy their needs, but salt was never produced commercially there. (Handbook of Texas Online, 2006a; 2006b; 2006c)

2.1.1 Streams

2.1.1.1 Elm Creek

Elm Creek (Segment 1803A) originates west of Nixon in the eastern part of Wilson County. The stream flows eastward for approximately 24 miles. It converges with Sandies Creek just west of the Sandies crossing with FM 1116. (See Figure 2.2) The stream traverses flat to rolling terrain of clay and sandy loam. The riparian vegetation consists of water-tolerant hardwoods and grasses.

2.1.1.2 Sandies Creek

Sandies Creek (Segment 1803B), formerly known as Castleman Creek, originates in southwestern Guadalupe County. The stream flows southeastward for approximately 65 miles until it joins with the Guadalupe River northwest of Cuero in DeWitt County. (See Figure 2.2) The creek traverses flat to rolling terrain with a surface of sand that gives the creek its name. The riparian vegetation consists of hardwoods, pines, mesquite, and a variety of grasses.

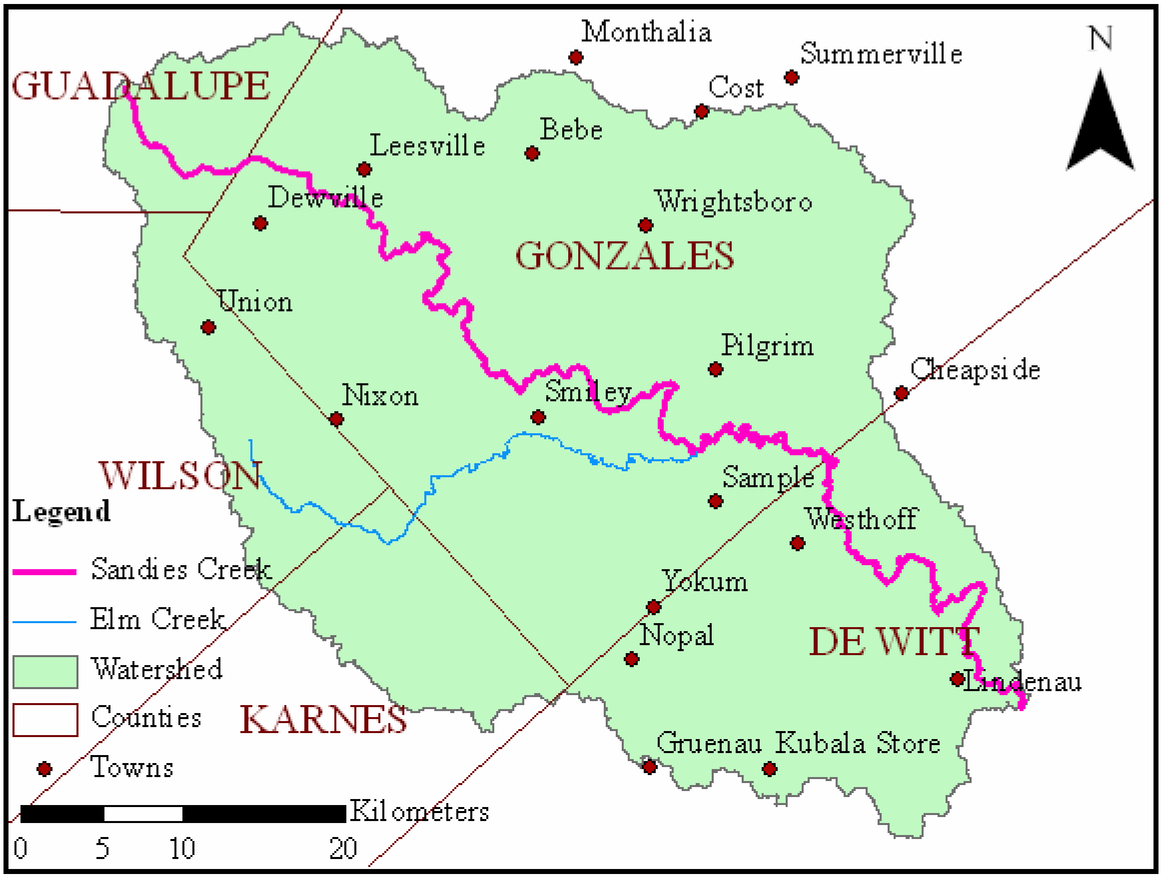

Figure 2.2: Sandies and Elm Creeks

2.1.1.3 Flow Characteristics

The drainage area associated with the USGS gauging station on Sandies Creek at Westhoff, Texas is 549 square miles and the annual average discharge is 145 CFS. But, as can be seen from Figure 2.3, the annual mean flow varies significantly from year to year. The annual average discharge ranges from 5.81 CFS in 1988 to 545 CFS in 1992.

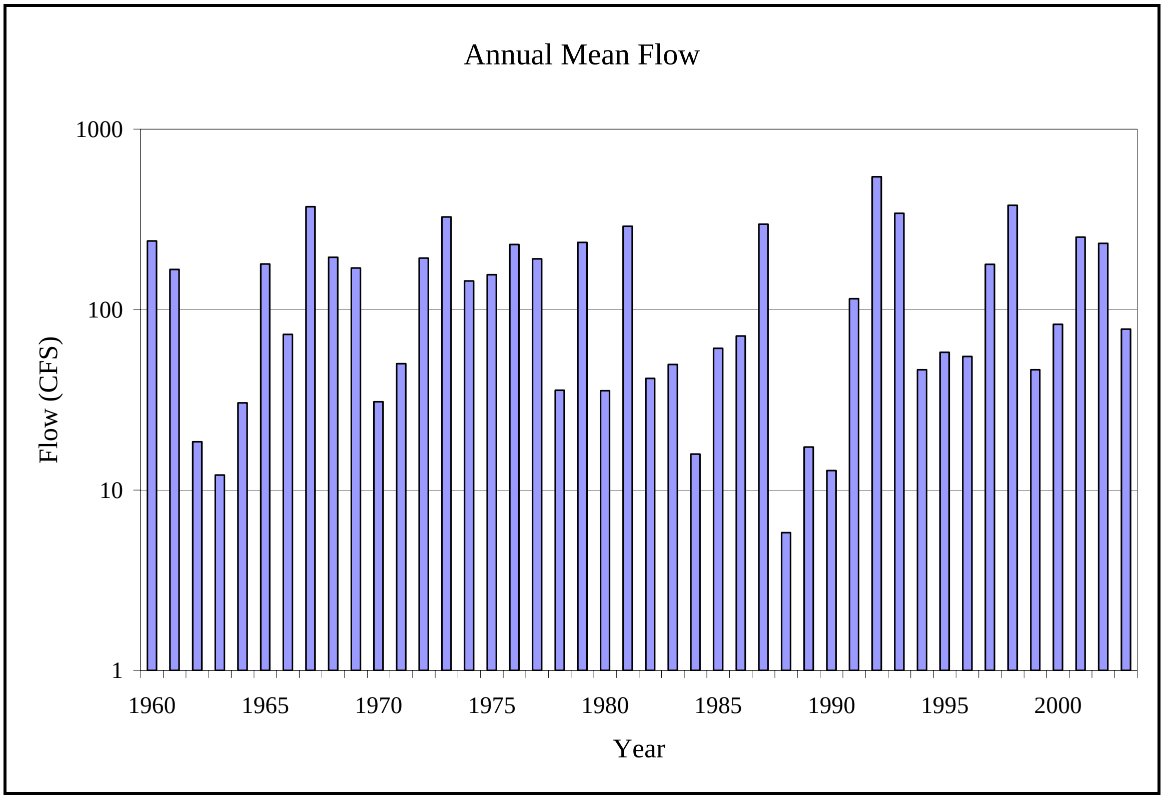

Figure 2.3: Annual Mean Flow (USGS: NWIS, 2005)

2.1.2 Climate

The climate in which the Sandies and Elm watershed is located is subtropical/sub-humid, with mild winters and hot summers. Temperatures in January range from an average low of 40° to an average high of 65° F and in July range from an average low of 74° to an average high of 96° F. The average annual precipitation across the watershed, as shown in Figure 2.4 below, ranges from 31 inches along the southwestern edge to 35 inches in most of the eastern portion of the watershed. There is no significant snowfall. The growing season averages 280 days per year, with the last freeze in February and the first freeze in early December. (Handbook of Texas Online, 2006a)

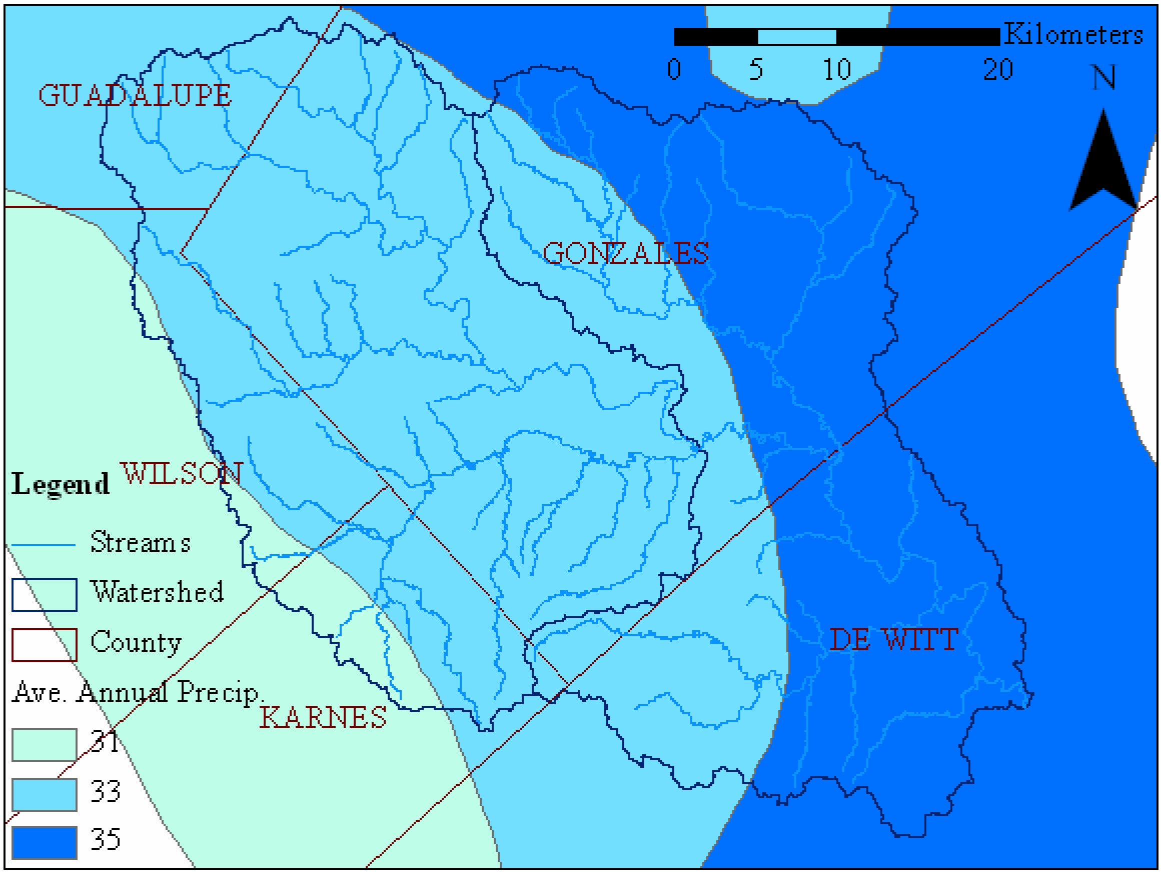

Figure 2.4: PRISM Average Annual Precipitation (inches)

2.1.3 Land Use / Land Cover

The watershed lies along the border of the Upper Coastal and Gulf Coast Plain in Southeast Texas. Vegetation consists primarily of grasslands, mesquite, blackjack, post oak, live oak, pecan, and some brush, thorny shrubs, and cacti in drier areas of the watershed, while water-tolerant hardwoods and conifers flourish near creeks. The natural vegetation of the watershed is examined more closely in the next section on Ecoregions.

According to USGS: Seamless (2006a) 1992 Land Use / Land Cover data, ninety-five percent of the land cover in the watershed is contained within four land use / land cover types: pasture, grassland, shrubland, and forest as shown in Figure 2.5. Although the majority of the watershed is agricultural, only five percent of the land in the county is considered farmland. The crops include peanuts, pecans, oats, wheat, sorghum, corn, vegetables, watermelons, and peaches. The largest industry in the watershed is livestock production; this topic is more closely examined in section 2.1.3.2 below.

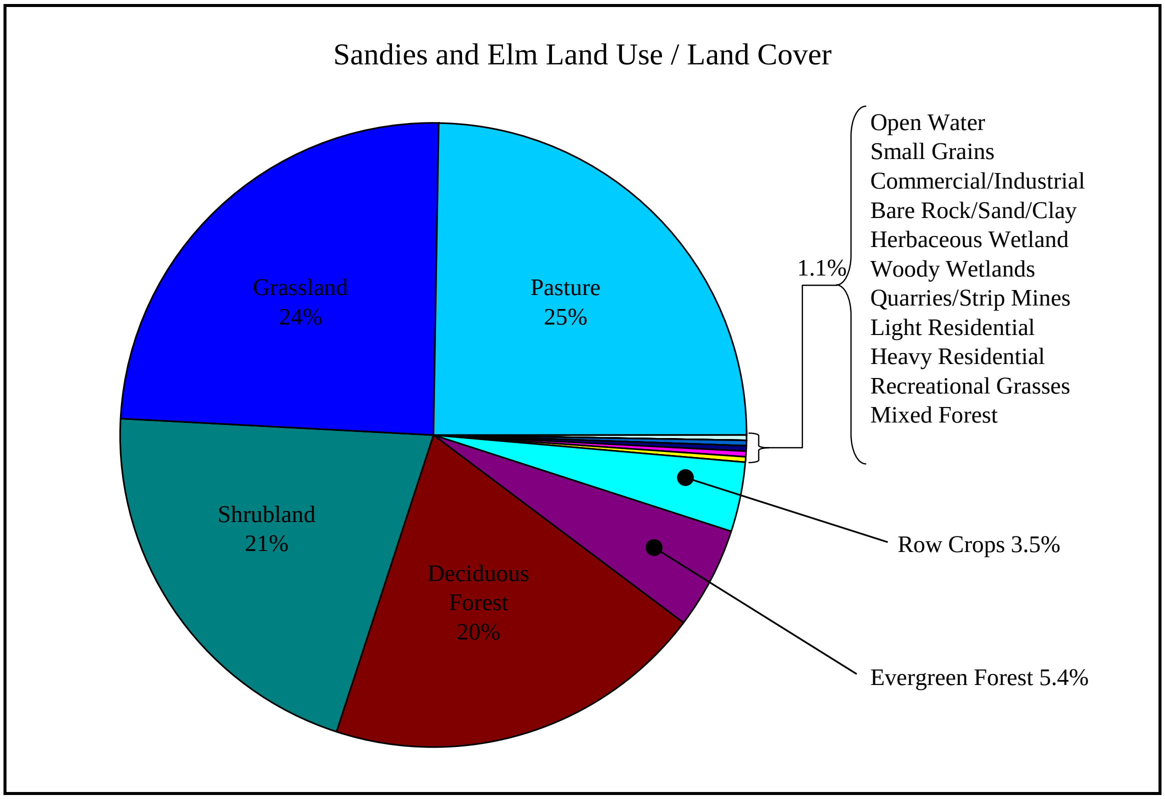

Figure 2.5: Sandies and Elm Land Use / Land Cover Breakdown

2.1.3.1 Ecoregions

As shown in Figure 2.6, the watershed lies within the following two Ecoregions: East Central Texas Plains and Texas Blackland Prairies.

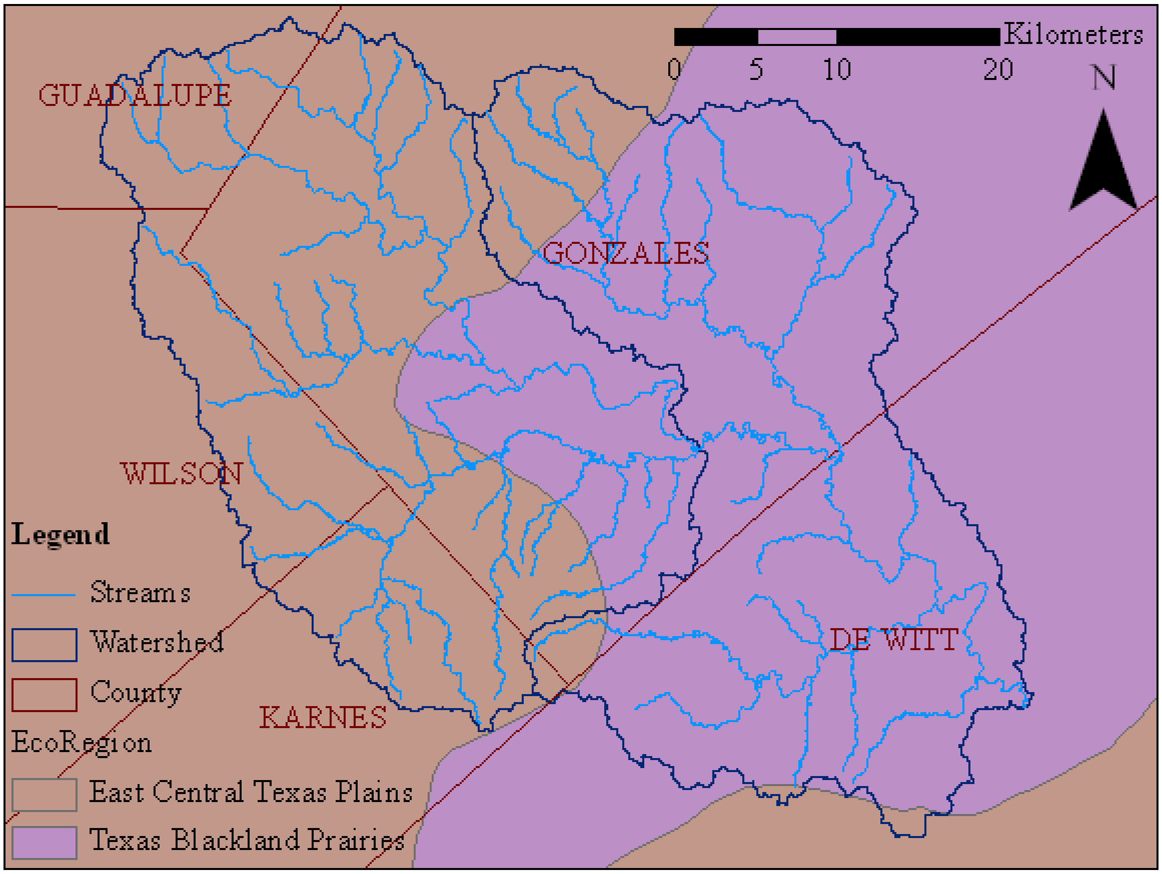

Figure 2.6: Sandies and Elm Ecoregions (US EPA, 2004)

The Texas Blackland Prairie Ecoregion is part of a tallgrass prairie continuum that stretches from Manitoba to the Texas Coast. The lower portion of the Sandies and Elm watershed is within the Southern Blackland Prairie, a separated subset of the Texas Blackland Prairies. (Griffith *et al*., 2004) The Blackland Prairie has a large degree of plant community diversity. This diversity is attributable to the ecoregion's variety of soil. These different soils have a variety of textures and a range of pH values. (Diamond et al., 1987; Diamond and Smeins 1985) The natural vegetation of the region was once dominated by tallgrass prairie on uplands with deciduous bottomland forest along the creeks. (Diamond and Smeins 1993; World Wildlife, 2006b) The dominant grasses include: little bluestem, big bluestem, yellow indiangrass, and switchgrass. (Griffith *et al*., 2004)

The Southern Post Oak Savanna is a subset of the East Central Texas Plains Ecoregion. This is sometimes referred to as the East Central Texas Forests (ECTF) and is located entirely within the state of Texas. It comprises one of the smallest ecoregions within the Temperate Broadleaf and Mixed forests biome. (World Wildlife, 2006a) The natural vegetation is a post oak savanna, currently the land cover is a mix of post oak woods with improved pasture and rangeland. Mesquite has been established as an invasive species in the southern portion of this area. A thick under story of yaupon and eastern red cedar are also prominent in some parts. (Griffith *et al*., 2004) This ecoregion is distinguished from the adjacent prairie units and coastal plain grasslands by a higher degree of tree density. (World Wildlife, 2006a)

2.1.3.2 Livestock

Livestock production accounts for a majority of the agricultural industry in the watershed. Livestock includes beef cattle, dairy cattle, poultry, and hogs.

According to the Texas Commission on Environmental Quality (TCEQ), poultry production, which is a possible source of non-point source pollution, is a significant industry in two of the five counties of the Sandies and Elm watershed. The area of significant poultry production is 572.8 square miles, which is 80% of the watershed. (See Figure 2.7) Gonzales County, which makes up 58.2% of the watershed, is the number three producer of broilers, the number one producer of layers, and the number four producer of turkeys in the state of Texas. (USDA: NASS, 2005) Yet, according to a Clean River Program report, "Poultry Operations Study Guadalupe River Basin," (GBRA-PBS&J, 1998) there was no detectable difference between this watershed and other nearby streams without poultry operations.

Table 2.1 shows the county breakdown of total livestock in the watershed. The livestock listed per county are the top five types of livestock according to the NASS 2002 Agricultural Census. The livestock type, Quail, was removed from Gonzales and Wilson Counties' lists because numbers were unknown. (USDA: NASS, 2005)

Overall, the largest livestock population in the watershed is chickens, with approximately five million broilers and two million layers. Coming in a distant third and fourth are cattle with approximately 130,000 head and turkeys with 107,000.

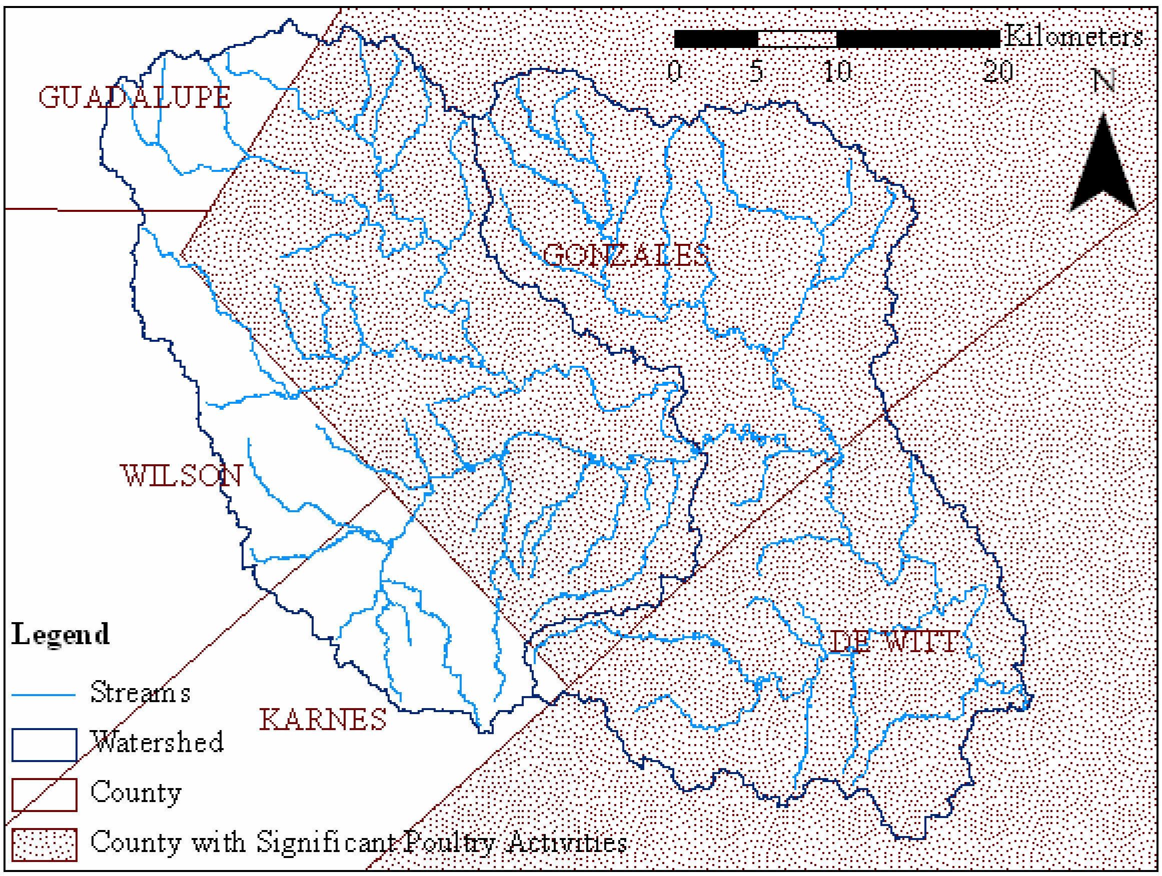

Figure 2.7: Counties with Significant Poultry Activity

Table 2.1: Livestock Counts for County Areas in Watershed and Watershed Total

DeWitt						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Cattle	21,090	20,424	20,646	19,536	25,974	25,086
Layers	15,009	14,303	14,590	17,918	17,505	17,692
Hogs	639	559	440	500	799	819
Horses	260	260	260	260	260	260
Goats	163	163	163	163	163	163
Gonzales						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Broilers	5,069,367	5,184,807	5,189,484	5,397,112	5,468,084	5,723,365
Layers	1,946,647	1,855,148	1,892,350	2,323,996	2,270,382	2,294,727
Turkeys	107,378	107,378	107,378	107,378	107,378	107,378
Cattle	88,464	94,284	92,538	89,628	94,284	97,776
Guadalupe						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Broilers	4,311	4,409	4,413	4,590	4,650	4,867
Layers	3,627	3,456	3,525	4,330	4,230	4,275
Cattle	2,548	2,499	2,450	2,450	2,940	2,744
Goats	172	250	348	245	279	260
Sheep	180	180	180	180	180	180
Karnes						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Cattle	4,968	4,680	4,680	4,608	5,400	5,328
Layers	3,587	3,418	3,487	4,282	4,183	4,228
Goats	115	108	144	122	166	151
Horses	70	70	70	70	70	70
Sheep	24	24	24	24	24	24
Wilson						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Cattle	6,450	6,900	6,675	6,225	7,275	7,050
Goats	105	105	128	113	165	150
Horses	156	156	156	156	156	156
Layers	107	102	104	127	125	126
Sandies and Elm Watershed						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Broiler	5,073,678	5,189,216	5,193,897	5,401,702	5,472,734	5,728,233
Layer	1,968,976	1,876,427	1,914,056	2,350,653	2,296,424	2,321,048
Cattle	123,520	128,787	126,989	122,447	135,873	137,984
Turkeys	107,378	107,378	107,378	107,378	107,378	107,378
Hogs	1,412	1,235	970	1,103	1,764	1,809
Goats	392	463	619	643	610	1,318
Horses	486	486	486	486	486	486
Sheep	88	74	64	49	880	1,117

2.2 WATER QUALITY OVERVIEW

Under Section 305(b) of the Clean Water Act (CWA) each state is required to assess the water quality in the water bodies within their borders on a periodic basis. This assessment is called the Water Quality Inventory. The Texas Clean Rivers Program (CRP), which is managed by the TCEQ, was created to oversee and improve the quality of surface water resources within the different river basins of Texas. The Guadalupe-Blanco River Authority (GBRA) and the Upper Guadalupe River Authority (UGRA) work in conjunction with the TCEQ to administer the CRP for the Guadalupe River Basin, in which the Sandies and Elm watershed is located, and Lavaca-Guadalupe Coastal Basin. The two river authorities carry out the water quality management efforts in these basins under contract with the TCEQ.

Each major river and lake within the state is classified by their designated uses by the state's water quality authority, in this case, the TCEQ. Each designated usage has a range of water quality criteria associated with it. The Water Quality Inventory assessment is based on a comparison between monitored field data and the range of criteria and screening levels associated with the designated uses. Streams that have an impairment for one or more constituents are placed on the TCEQ's CWA Section 303(d) list. Once a stream is placed on the list, a sequence of actions may be taken by the TCEQ, including, but not limited to:

1. Denial of increases in wastewater permit effluent limits
2. Total Maximum Daily Load (TMDL) study to allocate pollutant loads
3. Instituting a strategy for reducing loads from all sources.

The Sandies and Elm watershed is currently the subject of a TCEQ TMDL study due to the high amounts of bacteria and low dissolved oxygen content.

2.2.1 TMDL Overview

A TMDL is a tool for implementing state water quality standards. It is based on the relationship between sources of pollutants and in-stream water quality conditions. The TMDL establishes the allowable loadings for specific pollutants that a waterbody can receive without exceeding water quality standards, thereby providing the basis for states to establish water quality-based pollution controls. The TMDL can be generally described by the following equation:

Equation 2.1: TMDL Components

$$TMDL = LC = WLA + LA + MOS$$

where:
- LC = loading capacity,
- WLA = wasteload allocation,
- LA = load allocation, and
- MOS = margin of safety

The loading capacity is the largest pollutant loading a waterbody can receive without exceeding water quality standards for the designated usage. The wasteload allocation is the portion of the TMDL allocated for existing and future point sources. The load allocation is the portion of the TMDL allocated to existing and future non-point sources and natural background levels. The margin of safety accounts for uncertainty in the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity. (US EPA, 2001)

2.3 SANDIES AND ELM WATER QUALITY BACKGROUND

The Sandies and Elm Creeks have four designated uses. They are:

1. Aquatic Life
    a. Subcategory – High

b. Has NO known Federally Endangered or Threatened Aquatic Species

2. Contact Recreation

3. General

4. Fish Consumption

The “High” aquatic life subcategory designation represents a highly diverse habitat, with regionally expected species and some sensitive species present.

2.3.1 Concern Definitions

The term impairment is assigned by TCEQ to a water body when specific water quality constituents reach threshold concentrations, as specified in the Texas Surface Water Quality Standards, a number of times over a five years period.

Some water bodies are identified with the designation, “concerns for use attainment.” This designation is used for indicators that are directly linked to the support of designated uses, such as dissolved oxygen for aquatic life use.

There are two classifications under Use Concerns, Use Concerns and Use Concerns – Limited Data. Use Concerns are identified for indicators that support the designated use as determined by sampling greater than ten, but with few reported exceedances of the water quality criteria. Use Concerns – Limited Data is the same as Use Concern, except it is used when there are fewer than ten samples taken.

Secondary Concerns are identified for indicators such as nutrients that are not directly linked to the support of a designated use with quantitative criterion.

2.3.2 Impairments

Sandies Creek is impaired for aquatic life use due to depressed dissolved oxygen and contact recreation uses due to bacteria. It has use concerns for aquatic life use due to depressed dissolved oxygen and concerns for nutrient enrichment due to ammonia levels. Elm Creek is listed as impaired for aquatic life use due to depressed dissolved oxygen and contact recreation use due to bacteria. Figure 2.8 displays the segments and Table 2.2 lists each of the water segments with the designated use, concern classification, and parameter.

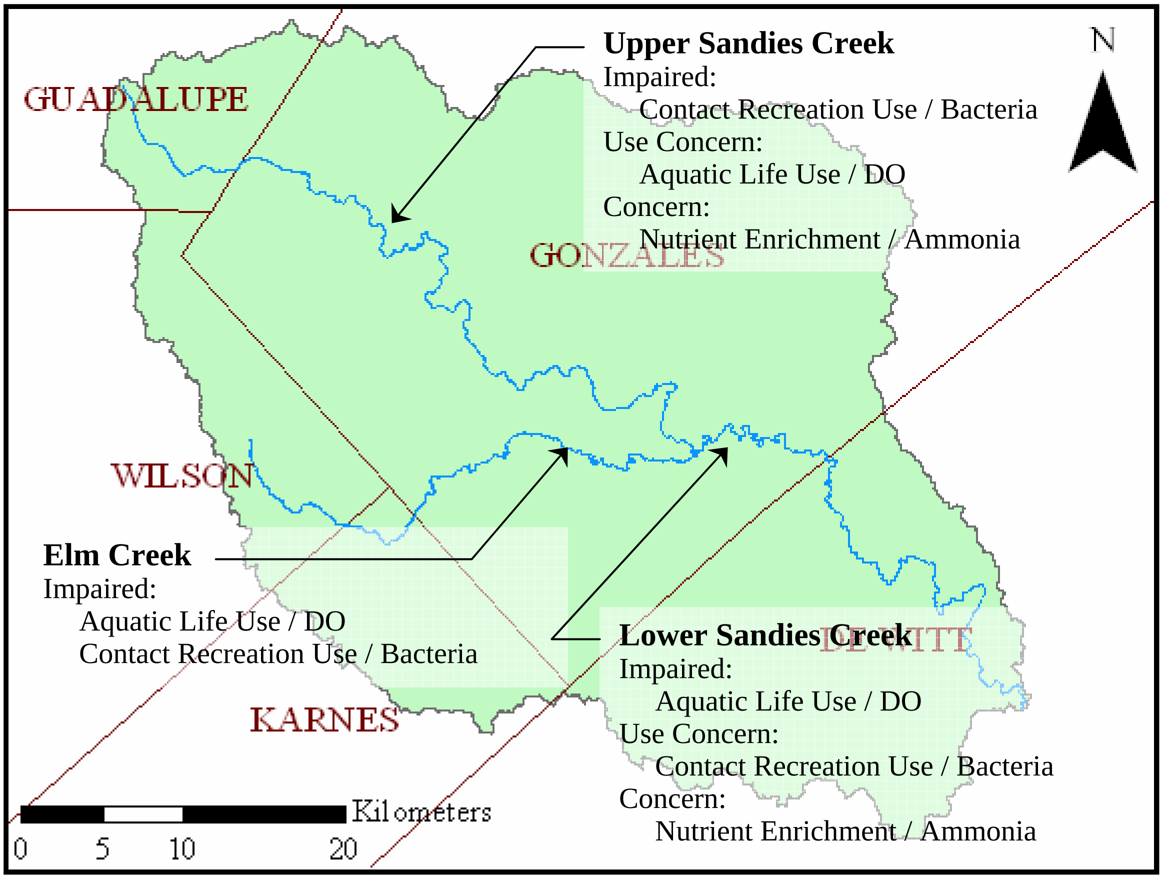

Figure 2.8: Usage Impairments and Concerns for the Sandies and Elm Creeks

Both the Sandies and Elm are small creeks and do not have water quality criteria developed for their unique hydrologic conditions. They are evaluated using the standards pertaining to the nearest downstream designated segment, in this case the Guadalupe River. But, the Guadalupe River has significantly different characteristics and dynamics than the Sandies and Elm Creeks.

Table 2.2: Sandies and Elm Impairment/Concerns (GBRA & UGRA, 2005)

Water Body ID	Water Body Name	Location	Use/Water Quality Concern	Impairment or Concern	Parameter
1803A	Elm Creek	Entire Water Body	Aquatic Life Use	Impaired	Depressed DO
1803A	Elm Creek	Entire Water Body	Contact Recreation Use	Impaired	Bacteria
1803A	Elm Creek	Entire Water Body	Narrative Criteria Concern	Concern	Depressed DO
1803B	Sandies Creek	From the confluence with Elm Creek to the upper end of the water body	Aquatic Life Use	Impaired	Depressed DO
1803B	Sandies Creek	From the confluence with Elm Creek to the upper end of the water body	Contact Recreation Use	Impaired	Bacteria
1803B	Sandies Creek	From the confluence with Elm Creek to the upper end of the water body	Aquatic Life Use	Use Concern	Depressed DO
1803B	Sandies Creek	From the confluence with Elm Creek to the upper end of the water body	Nutrient Enrichment Concern	Concern	Ammonia
1803B	Sandies Creek	From the confluence with Elm Creek to the upper end of the water body	Contact Recreation Use	Impaired	Bacteria
1803B	Sandies Creek	From the confluence with the Guadalupe River to the confluence with Elm Creek	Contact Recreation Use	Impaired	Bacteria
1803B	Sandies Creek	From the confluence with the Guadalupe River to the confluence with Elm Creek	Contact Recreation Use	Use Concern	Bacteria
1803B	Sandies Creek	From the confluence with the Guadalupe River to the confluence with Elm Creek	Aquatic Life Use	Use Concern	Depressed DO
1803B	Sandies Creek	From the confluence with the Guadalupe River to the confluence with Elm Creek	Nutrient Enrichment Concern	Concern	Ammonia

A Texas Clean Rivers Program study was undertaken by the Guadalupe Blanco River Authority in coordination with the engineering company PBS&J, to evaluate water quality non compliance of small streams. The report, “Unique Challenges Posed by

Small Streams in Determining DO and Bacteria Water Quality Criteria Compliance" (PBS&J, 2001), explained that the smaller the stream, the more non-attainment was observed. This is not unexpected since the criteria for the streams in Texas were developed for larger rivers, not for lower flow creeks a few inches deep. Several physical conditions exist in smaller streams that exacerbate an already problematic situation. The shallow water, which has less dissolved oxygen content than larger streams, also allows for less dilution when it is inundated with high bacteria runoff from a storm event. The percentage of shaded area is greater in smaller creeks than large rivers. This creates a higher temperature differential along the stream. The report concludes that an effort is needed to account for stream size and conditions and develop criteria appropriate to the higher natural variation and physical conditions of smaller streams.

2.3.3 Point Sources

According to the US EPA BASINS data for HUC 12100202, there are four permitted discharges into the Sandies and Elm Creeks, two domestic waste sources and two industrial waste sources. (US EPA, 2004) Figure 2.9 shows the locations for sources. The facility name and permitted flow are listed below in Table 2.3.

Table 2.3: Sandies and Elm Point Source Discharges

Map Label	Permit Number	Facility Name	Permitted Flow (MGD)	Remark
1	02013-000	Holmes Foods Nixon Proc. Plant		TX Land App. Permit
2	10234-001	City of Nixon WWTP	0.45	
3	10574-002	Smiley WWTP	0.042	
4	14458-001	Schertz Seguin Local Gov. WTP	0.75	

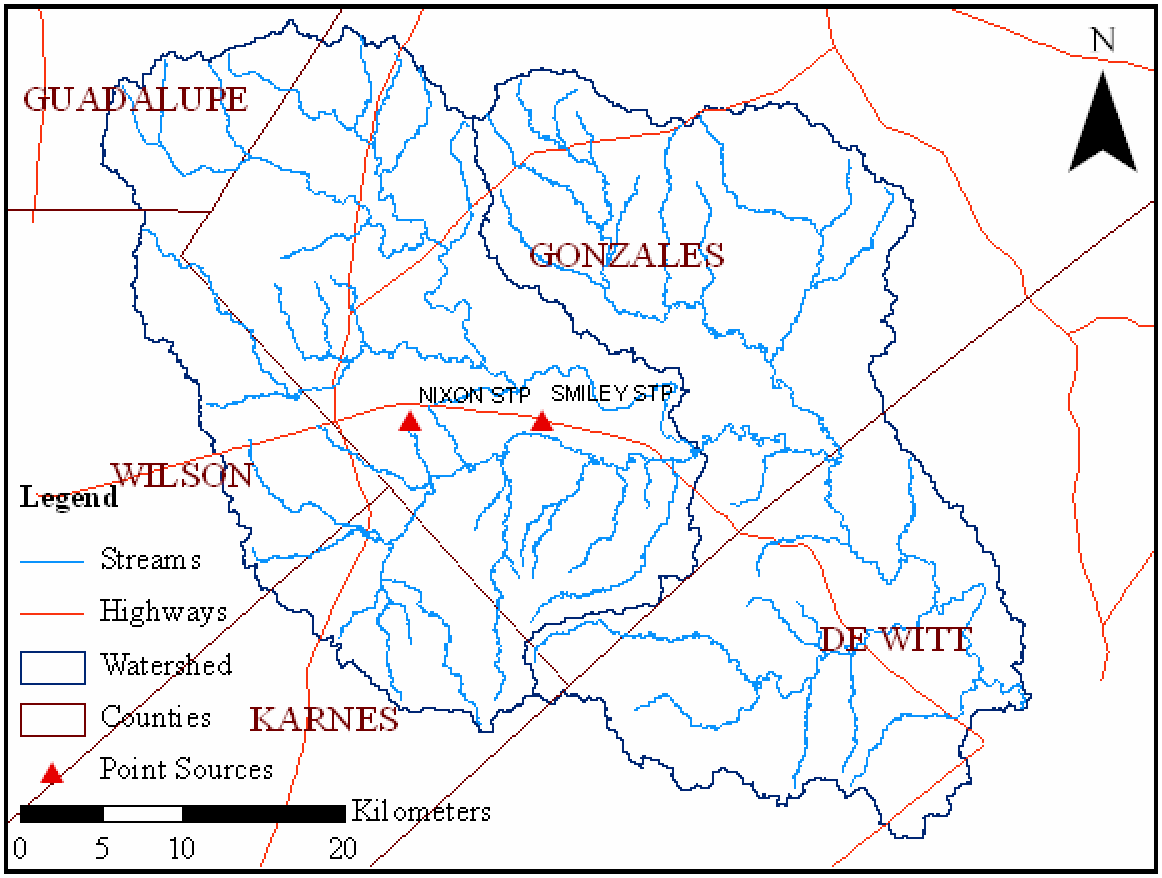

Figure 2.9: Sandies and Elm Point Sources (US EPA, 2004)

To assess the magnitude of both point and non-point sources of pollution on the streams in the Sandies and Elm watershed a TMDL study was initiated. For this study a watershed model that could accurately model the runoff from agricultural practices was needed. Hydrological Simulation Program – FORTRAN (HSPF) was chosen for this purpose. The next chapter discusses hydrologic modeling in general, and the history and structure of HSPF specifically.

Chapter 3 Hydrologic Simulation Program - FORTRAN

3.1 HYDROLOGIC MODELING OVERVIEW

There are two main purposes of hydrologic modeling. The first is to characterize current situations or predict conditions for which observed data does not exist. The second purpose is to lend insight into understanding the processes that are important in a system. Hydrologic engineers use their knowledge of known relationships between rainfall, runoff, infiltration, and evapotranspiration for river flow forecasting, flood insurance map creation, water availability studies, and reservoir/river management. Modeling for these uses allows interested parties to analyze the factors that affect the system response and make informed decisions in planning for future conditions.

Hydrologic models can be categorized in numerous ways. The important questions that must be addressed include:

1. Will uncertainty or randomness be accounted for in the model and if so, how?
   - Stochastic or Deterministic
2. Will spatial variation be included, and if so, to what extent?
   - Lumped or Distributed
3. Will time variation be allowed, and if so, what type?
   - Steady or Unsteady

The terms associated with mathematical model classification that answer these questions have very specific meanings which will be discussed below and are outlined in Figure 3.1, a model classification flow chart.

3.1.1 Stochastic or Deterministic

Most processes that occur in nature are not completely understood and mathematical depictions of these processes, therefore, contain levels of uncertainty.

Stochastic models explicitly account for uncertainty in model parameters. Deterministic models, on the other hand, characterize processes with specific values. Uncertainty is not considered in the processes they characterize, therefore the same set of input values will always give the same set of output values. HSPF is a deterministic model.

3.1.2 Lumped or Distributed

A further classification within deterministic models involves simplifications concerning spatial variability (Chow *et al*., 1988). A lumped parameter model does not clearly account for spatial associations between model parameters, inputs, or outputs. Lumped models typically have some degree of spatial resolution, but because they are most often spatial averages, the complexity of a model is reduced significantly. Distributed parameter models explicitly account for spatial relationships among model variables and parameters.

Lumped and distributed configurations for HSPF models should not be confused with the traditional definition of lumped and distributed models. No matter what the configuration, HSPF is essentially a lumped parameter model. (HydroComp, 2006b)

3.1.3 Steady or Unsteady

Another classification subset in mathematical modeling entails the time dependence of the processes characterized. Many deterministic hydrologic models make the assumption that flow is constant through time, which is defined as steady flow. Unsteady flow models allow for change in flow through the duration of the model run. This variability can complicate the hydrologic calculations considerably. (Chow *et al*., 1988) HSPF has the ability to be either a steady or an unsteady flow model.

3.1.4 Continuous or Event-Based

An additional distinction in the time series classification of a hydrologic model is that of continuous vs. event based modeling. In an event based model the model simulates the hydrologic response for a single rainfall event. An event based hydrologic simulation requires that the initial hydrologic conditions of the landscape be known. But it only requires forcing data for the duration of the event to be modeled. Continuous hydrologic models are required to keep track of the changes in the hydrologic conditions of the landscape that affect rainfall-runoff response between storm events. An example of such a condition is soil moisture, which is an important component in infiltration and runoff processes. Initial conditions are also required for a continuous model; however, the results from a continuous model become less dependent upon these initial conditions over longer simulation periods. (HydroComp, 2006b)

3.1.5 HSPF Model Classification

Hydrologic Simulation Program – FORTRAN (HSPF) is a deterministic, lumped-parameter, physically based, continuous model for simulating the water quality and quantity processes that occur in watersheds and in a river network.

In reality, because environmental processes are occurring continuously in space and time, they are tremendously complicated to simulate precisely. If environmental processes were completely understood, a mathematical model could be developed that is physically base, continuous, deterministic, and distributed. The model would be able to forecast precisely the reaction at every point in a watershed with input data such as rainfall, evaporation, and pollutant deposition.

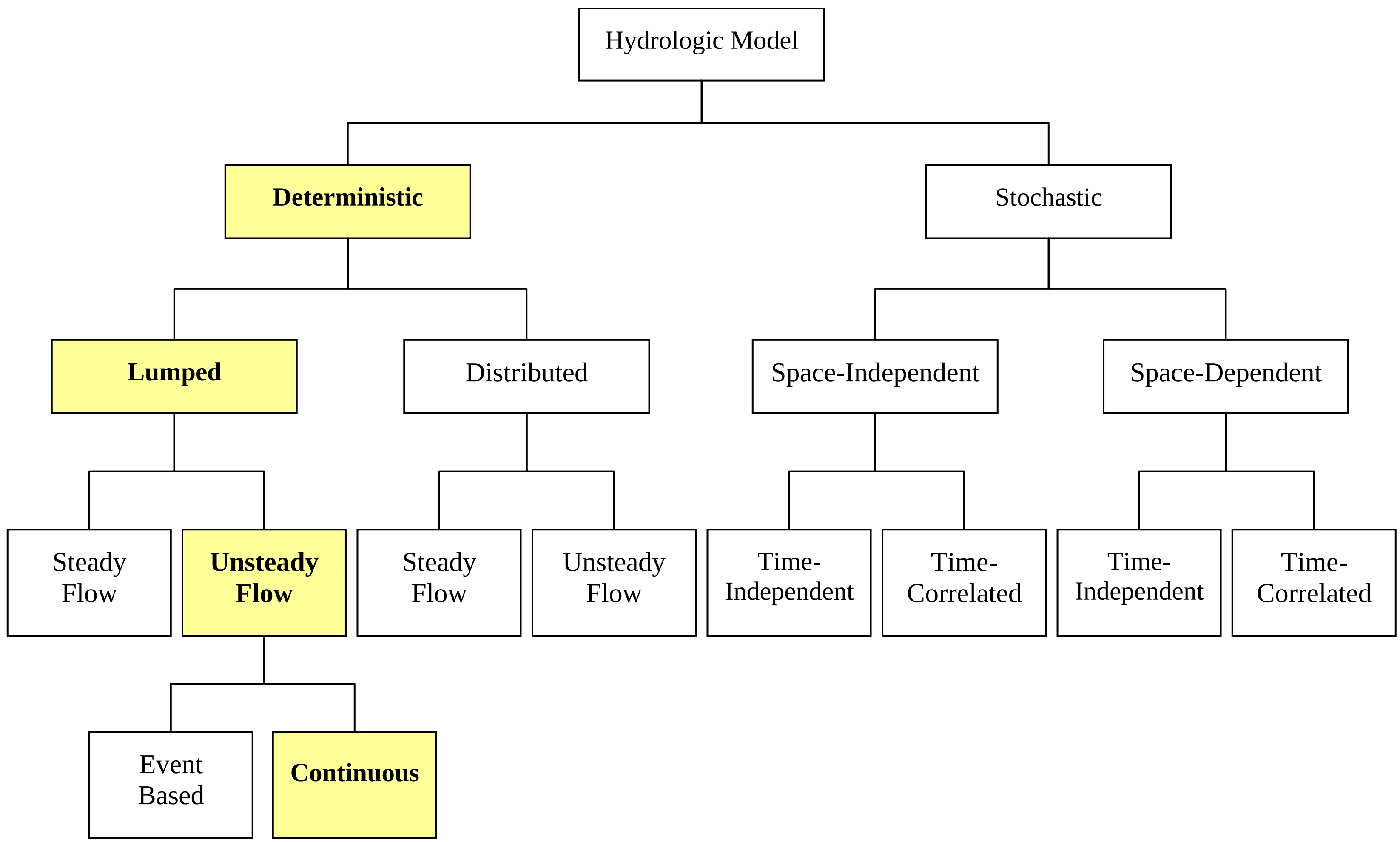

Figure 3.1: Hydrologic Model Flow Chart [Adapted from Figure 1.4.1 (Chow *et al.*, 1988)]

Unfortunately, at this time the governing processes of the natural environment are not completely understood. Therefore, HSPF and every other hydrologic and water quality model rely on varying levels of spatial, temporal, and process averaging to predict the response in a watershed. These mathematical models were developed to simulate processes as accurately as possible considering the limitations of the available data as well as an imperfect understanding of the underlying processes. (Chow *et al.*, 1988)

3.2 HISTORY OF HSPF

HSPF is based on the Stanford Watershed Model developed by Crawford and Lindsley in 1966. A flowchart of the Stanford Watershed Model is presented in Figure 3.2.

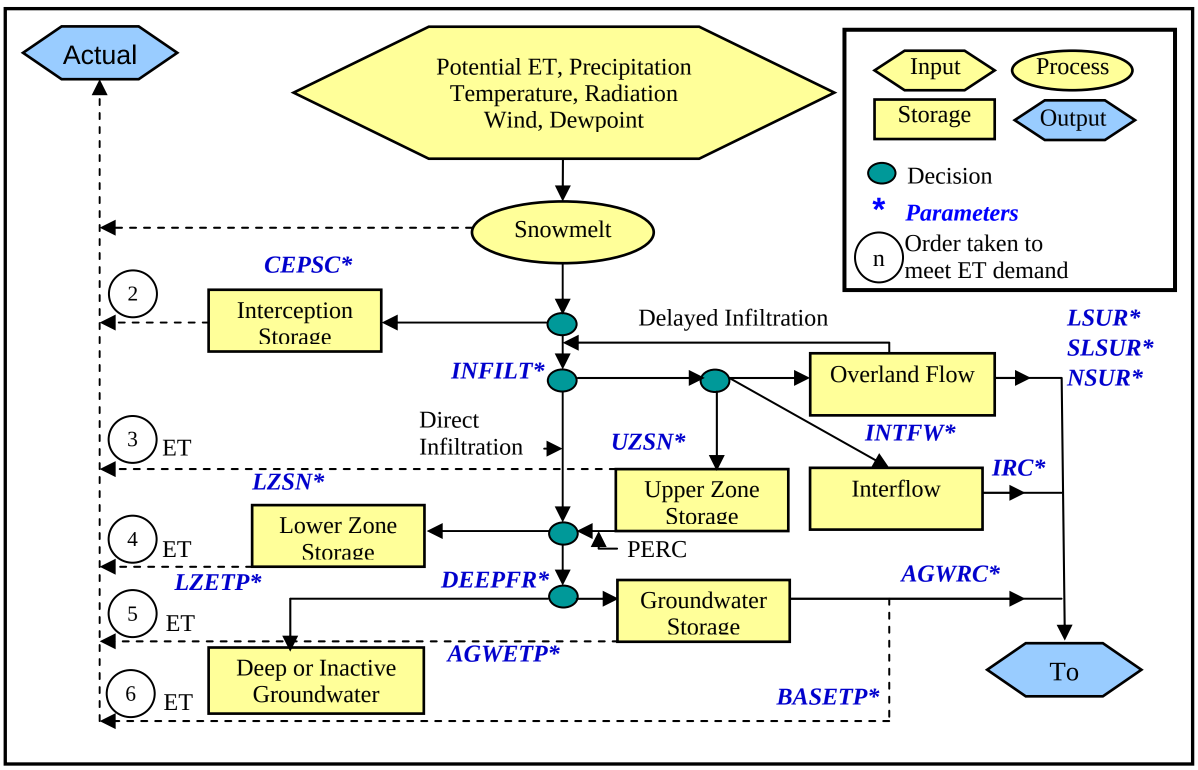

Figure 3.2: Stanford Watershed Model (AquaTerra, 2005)

The developers of the Stanford Watershed Model made improvements on their original model and created the HydroComp Simulation Program (HSP), which included sediment transport and water quality simulation. During the early 1970s other field level based watershed water quality programs were also being developed: the Environmental Protection Agency's Agricultural Runoff Management (ARM) Model (Donigian and Davis, 1978) and the Nonpoint Source Pollutant Loading (NPS) Model (Donigian and Crawford, 1979).

During the latter part of the 1970s the EPA funded and directed the creation of a single program that could perform all of the functions included in HSP, ARM, and NPS. The result of this effort was HSPF, which was first released publicly in 1980, 26 years ago. HSPF is considered to be one of the first comprehensive watershed models. It is widely used and has undergone many modifications and additions over its lifetime.

Just after the release of HSPF, the USGS began developing software to help facilitate watershed modeling by providing interactive capabilities for model input development, data storage, data analysis, and model output analysis. ANNIE, WDM, Scenario Generator (GenScn), and HSPEXP are all USGS software products. They have facilitated watershed model creation, analysis, and report creation.

Throughout the 1980s and 1990s, HSPF went through a series of algorithm and code enhancements, which have culminated in the current release version 12. (Bicknell *et al.*, 2001) Although data requirements are extensive and learning to correctly use the model requires a significant amount time, the Environmental Protection Agency recommends its use as the most appropriate management tool available for the continuous simulation of hydrology and water quality in watersheds.

In 1994 development began for EPA's Better Assessment Science Integrating Point and Non-point Sources (BASINS) modeling system. BASINS provides a full range of tools and data which are integrated into a single modeling package that includes environmental databases, accepted EPA models, assessment tools, processing utilities, and report generating software. Today the HSPF/BASINS package serves as a focal point for cooperation and integration of watershed modeling and model support activities between the USGS and the EPA.

HSPF is currently one of the most comprehensive and flexible models of watershed hydrology and water quality available. It is one of a small number of available models that can simulate a continuous, dynamic event, or steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed with an integrated linkage between surface, soil, and stream processes. (AquaTerra, 2005)

3.3 HSPF OVERVIEW

Hydrologic Simulation Program – FORTRAN (HSPF) is an analytical tool that has applications in the design, management, and operation of water resources systems. HSPF uses forcing data such as rainfall, temperature, and evaporation, as well as parameters related to land use patterns, soil characteristics, and agricultural practices to simulate the processes that occur in a watershed. HSPF simulates a timeseries of the quantity and quality of water transported over the land surface and through various soil zones and groundwater aquifers to the stream network. Runoff flow rate, sediment loads, nutrients, pesticides, toxic chemicals, and other water quality constituent concentrations can be predicted. HSPF can then produce a timeseries of water quantity and quality at any initially specified point in the watershed.

3.3.1 HSPF Perspective of the Hydrologic Cycle

Within the HSPF modeling environment the movement and storage of water is conceptualized as presented in Figure 3.3. The major characteristics of the modeled hydrologic cycle are precipitation, evapotranspiration, land use / land cover, vegetation and soil type, groundwater qualities, and the river network.

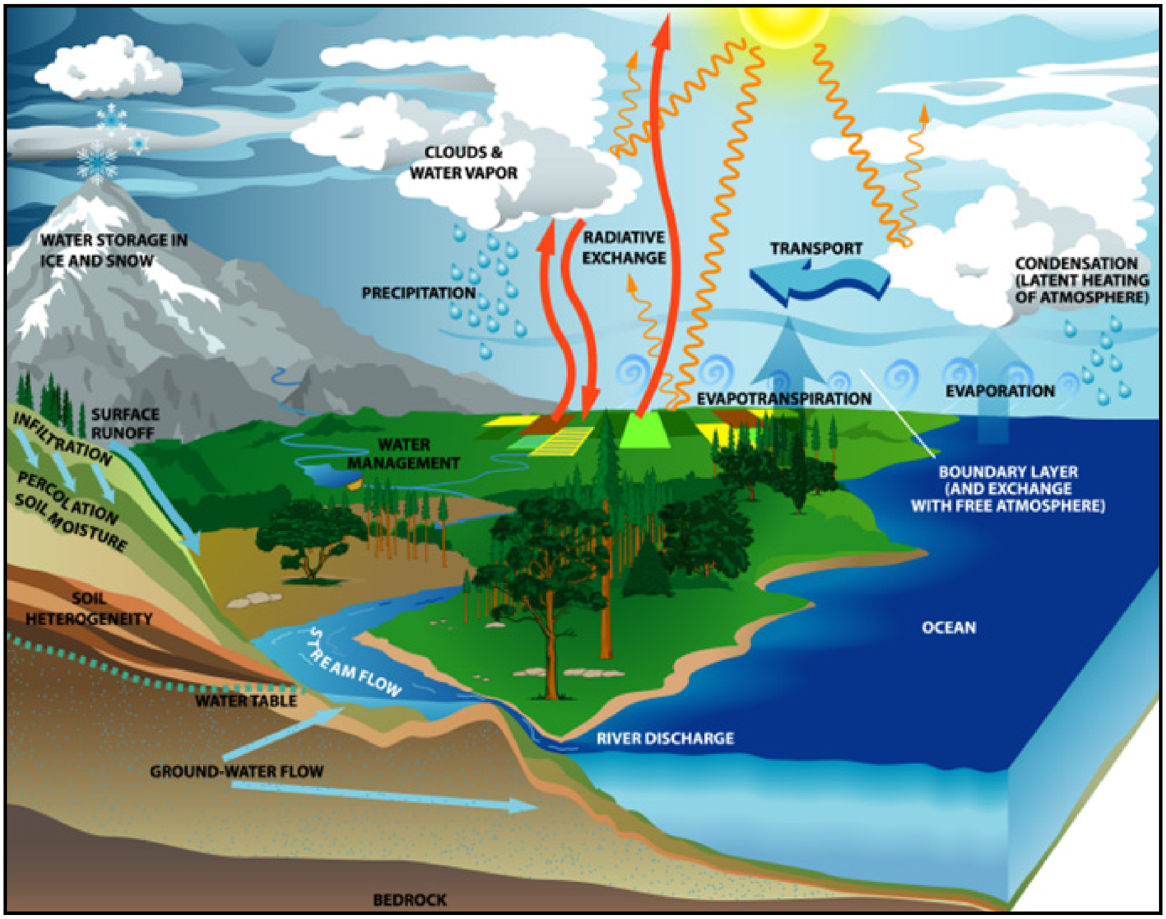

Figure 3.3: Hydrologic Cycle

In HSPF, hydrologic processes are characterized mathematically as flows and storages. Typically, each inflow is an outflow from a storage, which includes groundwater, soils, and even the river reach itself. This relationship is usually expressed as a connection between the current storage amount and the physical characteristics of the subsystem. Although, for the most part, HSPF is based on physical characteristics, it has many processes that are represented by abridged or theoretical approaches. Although this method requires that parameters be calibrated, there is an advantage in avoiding computation of all of the physical characteristics of the watershed.

The watershed, in an HSPF model, is represented in terms of land segments and water bodies. In general, a particular land segment is defined by having similar hydrologic characteristics. Water, sediment, and chemical and biological pollutants move laterally downslope as they flow across the watershed toward a different land segment or reach. In HSPF, land segments can be defined as either pervious or impervious. Each segment of land that has the capacity to allow infiltration is considered pervious, otherwise it is considered impervious. Pervious and impervious land segments are simulated independently in HSPF.

The soil environment, within a pervious segment, is divided into three major groups: upper zone, lower zone, and intermediate zone. Vegetation influences the movement of water into and out of this soil environment through interception and transpiration. Below the soil zone, groundwater is divided into two zones: an active groundwater zone, which may discharge to streams, and an inactive groundwater zone, which recharges the aquifer.

3.3.2 HSPF Application Modules

HSPF simulates the processes in and of water through the watershed with three application modules and eight utility modules. The three application modules simulate the hydrology/hydraulic and water quality components of a watershed. They are PERLND, IMPLND, and RCHRES. PERLND simulates the runoff and water quality constituents from pervious land segments. IMPLND simulates the runoff and water quality constituents from impervious land segments. RCHRES simulates the movement of water and water quality constituents in streams and impoundments. See Table 3.1 for the list of modules and their associated uses.

Table 3.1: Modules and Associated Uses (Bicknell *et al*., 2001)

Application Modules	PERLND	Snow, Water, Sediment, Soil Temperature, Water Quality, Pesticide, Nitrogen, Phosphorus, Tracer
	IMPLND	Snow, Water, Solids, Water Quality
	RCHRES	Hydraulics, Conservative, Temperature, Sediment Non-conservatives, BOD/DO, Nitrogen, Phosphorous, Carbon/pH, Plankton
Utility Modules	COPY	Data Transfer
	PLTGEN	Plot Data
	DISPLAY	Tabulate, Summarize
	DURANL	Duration
	GENER	Transform or Combine Timeseries Data
	MUSTIN	Timeseries Data
	BMP	Compute pollutant removal via control measures
	REPORT	Customize and view model report

3.3.3 PERLND Module

PERLND is the most frequently used module in HSPF because it simulates the activities in pervious land segments. Water can move within the PERLND module along one of three paths: overland flow, interflow, and groundwater flow. These paths each have different water release delay parameters and interaction with water quality constituents.

Figure 3.4 defines the structure and components of the PERLND module. The PERLND module features individual subroutines for specific modeling purposes.

The PWATER subroutine in the PERLND module is used to calculate the water budget components resulting from water movement in, out, and through pervious land segments. As a result it is the key component of the PERLND module.

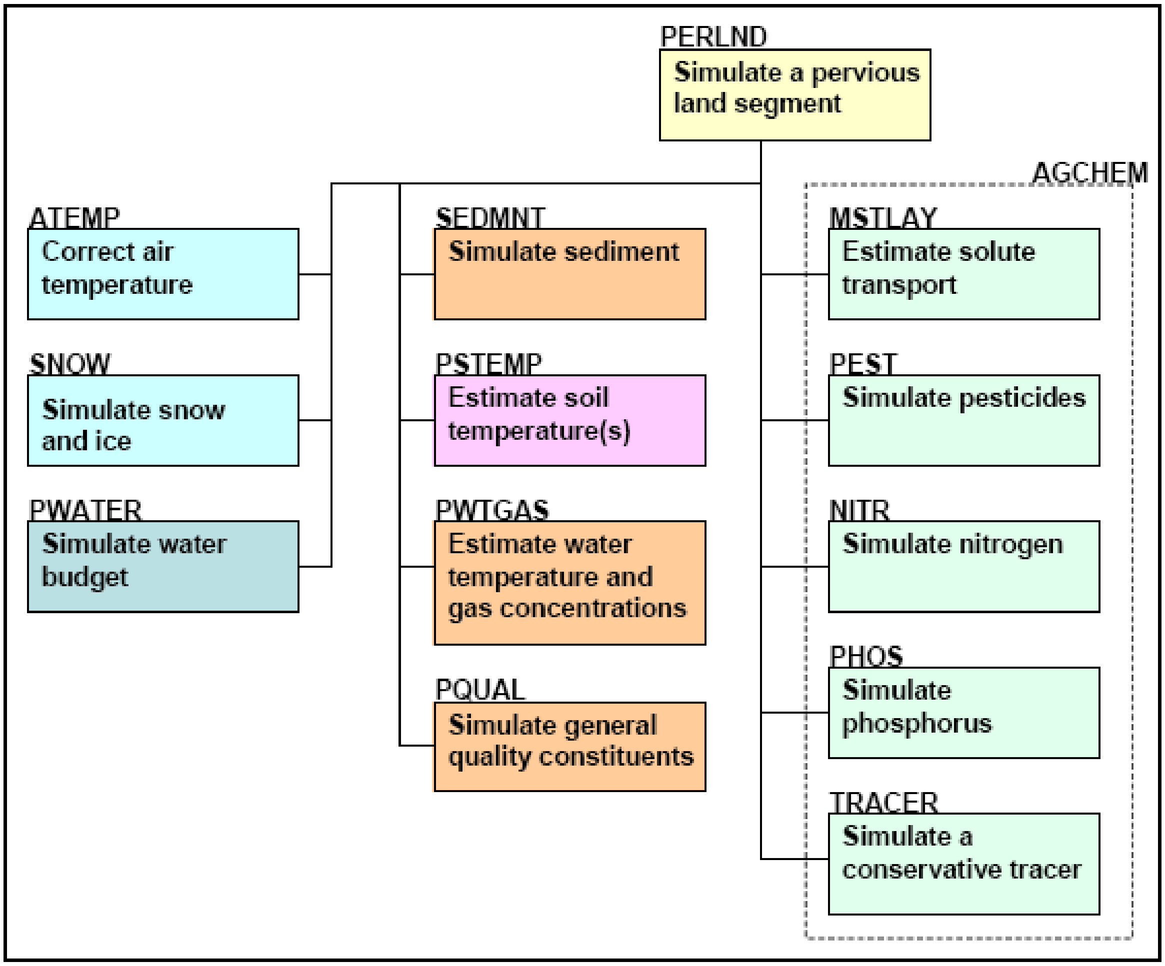

Figure 3.4: PERLND Structure Chart (AquaTerra, 2005)

The only other component used in this TMDL study was PQUAL. It simulates general water quality constituents, including Fecal Coli Form bacteria, in the outflows, both on and below the surface, of a pervious land segment using simple relationships with water and/or sediment yield. HSPF allows quantities in surface outflow to be simulated by either one or both, of the two available methods. The first is to use a "potency factors" to indicate constituent strength relative to the sediment removal computed by SEDMNT. The second is to model the storage of a constituent on the land surface, considering the accumulation and depletion or removal of the constituent, with a first-order wash off rate of the remaining constituent removed by overland flow after a storm event, which is computed by PWATER. Both formulations can be used to represent the wash off behavior of particulate and dissolved components of specific pollutants.

3.3.4 IMPLND Module

The IMPLND module is used for impervious land surfaces, which consist mainly of urban land use categories where little or no infiltration occurs. Water, solids, and various pollutants are removed from the IMPLND land surfaces by the lateral movement of water down slope to another land segment, a stream channel, or a reservoir. A complete layout of the IMPLND structure is shown in Figure 3.5.

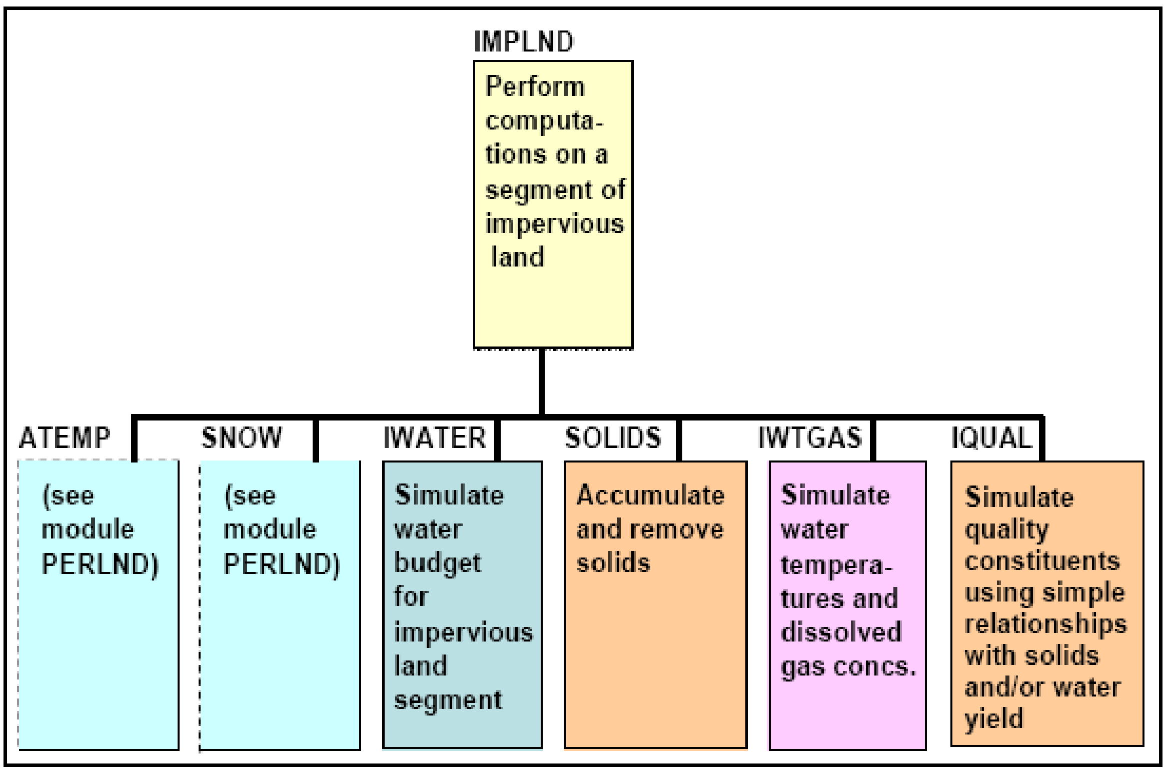

Figure 3.5: IMPLND Structure Chart (AquaTerra, 2005)

The main subroutine in IMPLAND is IWATER, which calculates the water budget in an impervious land segment. IWATER was the only subroutine used in the HSPF model for this study.

3.3.5 RCHRES Module

The RCHRES module is used to route runoff and water quality constituents simulated by PERLND and IMPLND through stream channel networks and reservoirs. This module simulates the processes that occur in a series of open or closed channel reaches or completely mixed impoundments. The flow in a water body is modeled as unidirectional. A number of processes can be modeled, they include hydraulic behavior and DO and BOD balances. Figure 3.6 defines the structure and contents of the RCHRES module.

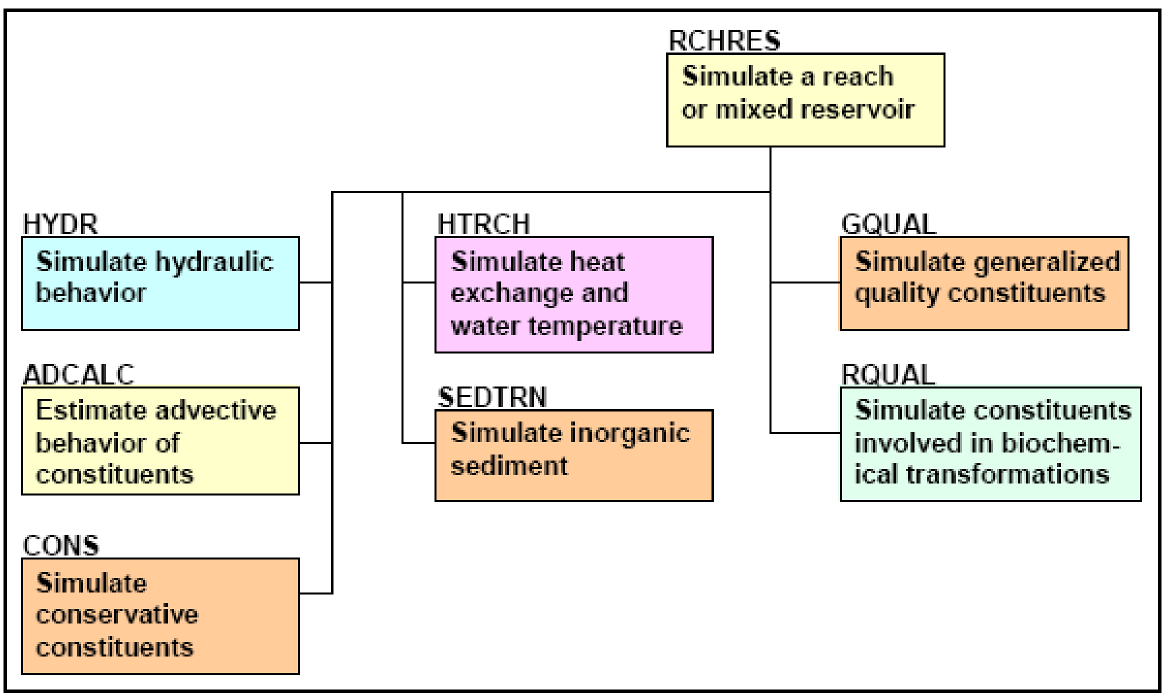

Figure 3.6: RCHRES Structure Chart (AquaTerra, 2005)

The HYDR subroutine of the RCHRES module simulates the processes that occur in a single reach of an open channel or completely mixed impoundment. The hydraulic behavior is modeled using the kinematic wave method; therefore the momentum of flow is not considered. All the inflows into a reach are assumed by HSPF to enter at a single upstream point. The outflow of a single reach may be distributed across several outlets that represent normal outflows, diversions, or multiple gates in a reservoir. In HSPF, outflows can be represented by either, or both of two methods. First, the outflow can be modeled as a function of reach volume for situations in which there are no controls on flows, or gate settings are only a function of water level. Second, the outflow can also be simulated as a function of time to represent demands from municipal, industrial, or agricultural use.

There are no assumptions as to channel shape, but HSPF does make two assumptions for stream hydraulics. First, there is, for every reach, a preset, user-defined relationship between water depth, surface area, volume, and discharge. This is specified in the Function Table (FTABLE) of the .uci file. Second, for any outflow demand with a volume-dependent component, the relationship between the four variables listed above is typically constant in time. However, seasonal or daily variations in discharge values can be input by the user.

3.4 CLOSING

The U.S. Environmental Protection Agency recommends the use of HSPF for hydrologic and water quality watershed process modeling because of its ability to calculate multiple water quality constituents continuously in an unsteady flow environment. These characteristics make HSPF an ideal model for many different types of watersheds across the United States and the world. But it also makes HSPF an extremely complex model, which requires a good deal of time and effort to master.

Even though the parameters, for the most part, are physically defined there are still a number of them which are undefined and must be calibrated. The vagaries in these parameters can often be used to compensate for the unknowns characteristics of the physical system or the lack of precision and accuracy in the known data.

The structural construction of HSPF takes into account the lack of complete understanding of the physical system in which water and pollutants interact and travel. It was created at a time in which the known physical system characteristics could not be defined at the detailed spatial resolution that is obtainable today. Limitations in the coded structure of HSPF reduce the advancements in hydrologic modeling which could be made given the readily accessible spatial and temporal data now available.

Chapter 4 Motivation

The forcing data required for a simple hydrologic model in HSPF are precipitation and evaporation. Traditionally, weather data is acquired from single point gauges and applied using Thiessen polygons over the modeled watershed area. This technique is standard practice and adequate in a climate with a significant amount of frontal weather systems or a densely gauged area. The Sandies and Elm watershed is located in a semi-arid climate known for significant convective storm events. The flow variability of the streams is defined by these convective storm systems. Bacteria and dissolved oxygen monitoring were performed on a storm event basis. The model needs to be calibrated to these storm events, and therefore the storm event data input into the model should be accurately represented with reference to both volume and spatially distribution.

4.1 PRECIPITATION DATA SOURCES

There are multiple available sources of archived precipitation data. Each has strong and weak points associated with use in a hydrologic model. Some are spatial in nature, others are point driven. Brief descriptions of the different sources are discussed below.

4.1.1 NCDC

In the United States, the National Oceanic and Atmospheric Administration (NOAA) operates the National Climate Data Center (NCDC) whose function is to collect, archive, quality assess, and disseminate conventional surface and upper air data needed for national and international environmental research programs. (Shea *et al.*, 1994)

The NCDC is the traditional source of the forcing data that is required by HSPF. The NCDC has a vast array of information available for download from their website, www.ncdc.noaa.gov. This information includes reports, analysis, summaries, and averages for both event, mean, and interval weather and climate related data. NCDC has many stations across the United States that gather this data. Depending on the order of the station, different intervals of data are collected. The recording intervals include hourly, daily, monthly, and annual. Acquiring information on anything greater than a daily time step would be unreasonable for continuous model output.

4.1.1.1 Daily

A search of NCDC precipitation stations was conducted in the five county area surrounding the 712 square mile Sandies and Elm study area. There are 1,436 NCDC daily stations available in Texas. Twenty-seven (27) of these stations are located in the five county area surrounding the Sandies and Elm watershed as shown in Figure 4.1. Of these 27 stations, 15 had data available for 2000 through 2004, but only one, Nixon, is actually located in the Sandies and Elm watershed as indicated in Figure 4.2. Unfortunately, Nixon precipitation data is missing for October 2002 through November 2004.

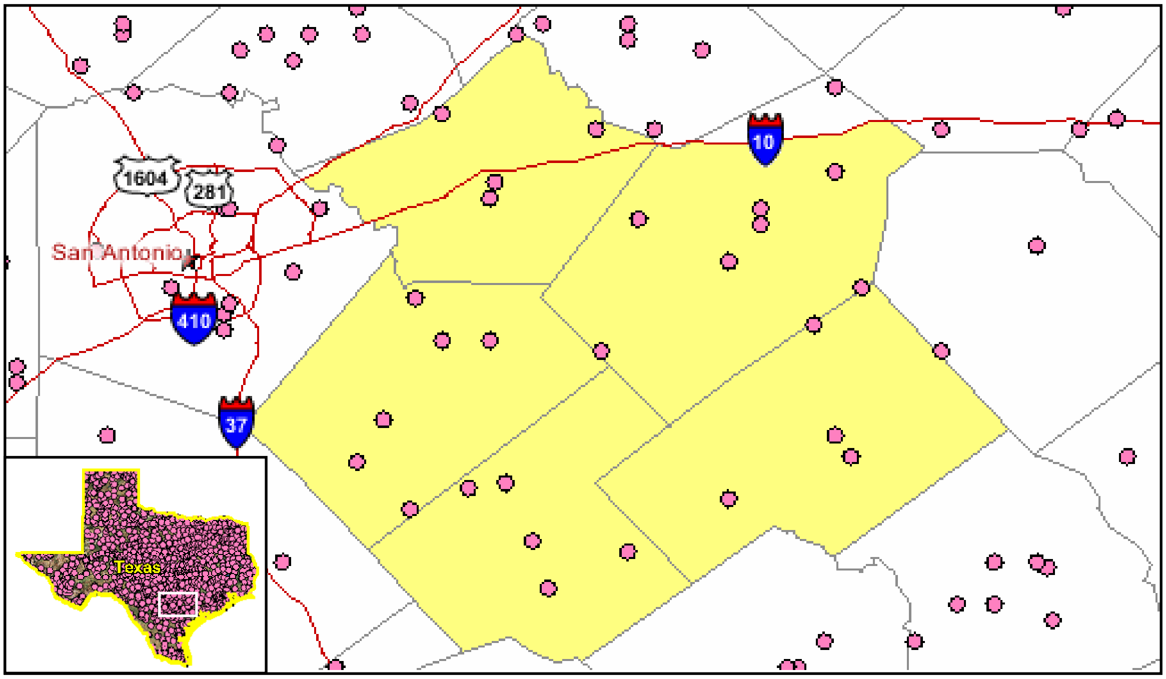

Figure 4.1: Available NCDC Daily Precipitation Stations (NOAA: NCDC, 2006b)

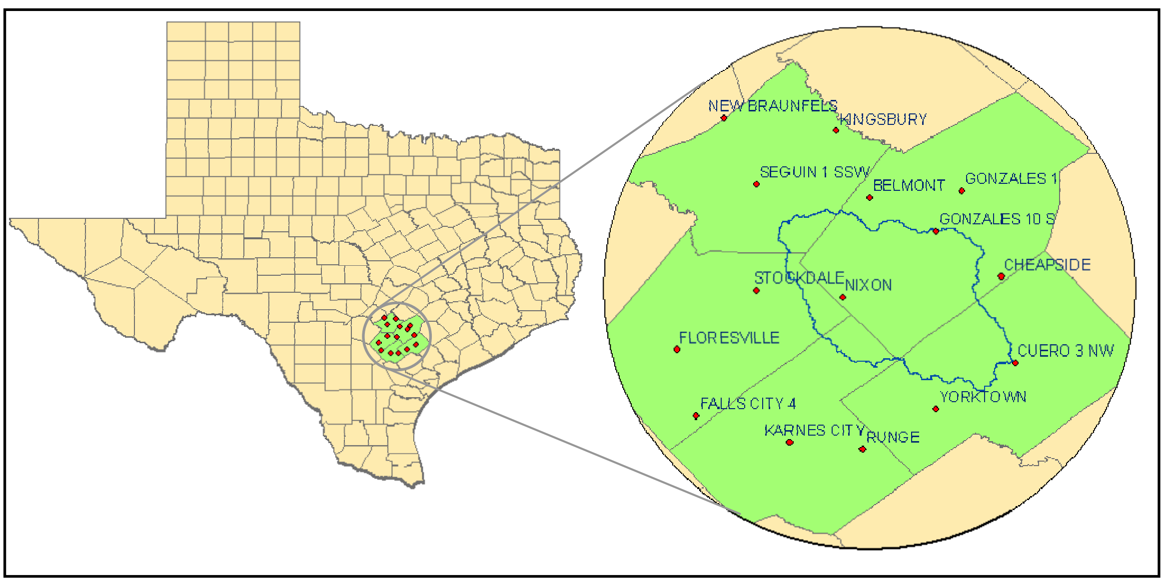

Figure 4.2: Available NCDC Daily Precipitation Stations for years 2000 thru 2004

4.1.1.2 Hourly

There are 525 NCDC hourly stations available in Texas. Three of these stations are located in the five county area surrounding the Sandies and Elm watershed. See Figure 4.3 below. Of these three stations only one, Cheapside, had data available for 2000 through 2004. The Cheapside station was located near, but not in, the Sandies and Elm Watershed (See Figure 4.2).

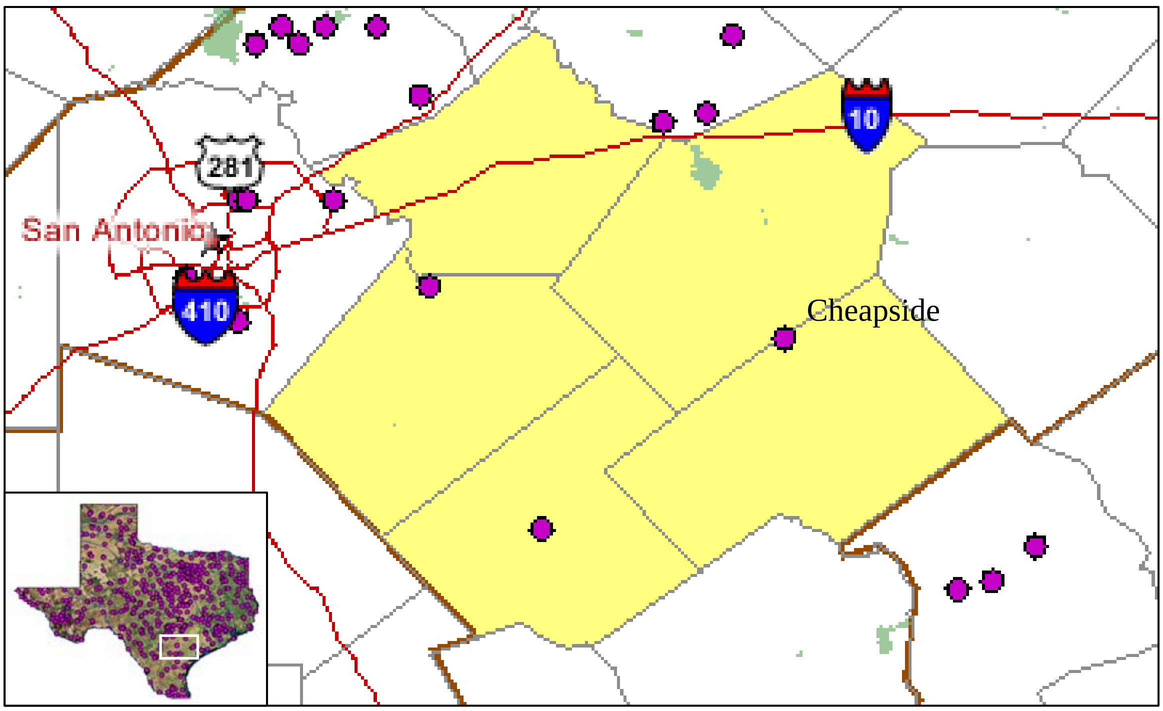

Figure 4.3: Available NCDC Hourly Precipitation Stations (NOAA: NCDC, 2006b)

4.1.2 NEXRAD

The most effective tool to detect spatial coverage of precipitation is RADAR. RADAR, which stands for RAdio Detection And Ranging, has been used to detect precipitation, and especially thunderstorms, since the 1940's.

NEXRAD, which stands for NEXt Generation RADAR, is a Doppler RADAR. The National Weather Service's Doppler RADARs can detect most precipitation within approximately 90 miles of the RADAR (as indicated by the size of the circles shown in Figure 4.4) and intense rain or snow within approximately 155 miles. However, light rain, light snow, or drizzle from shallow cloud weather systems is not necessarily detected. (Weather Underground, 2006)

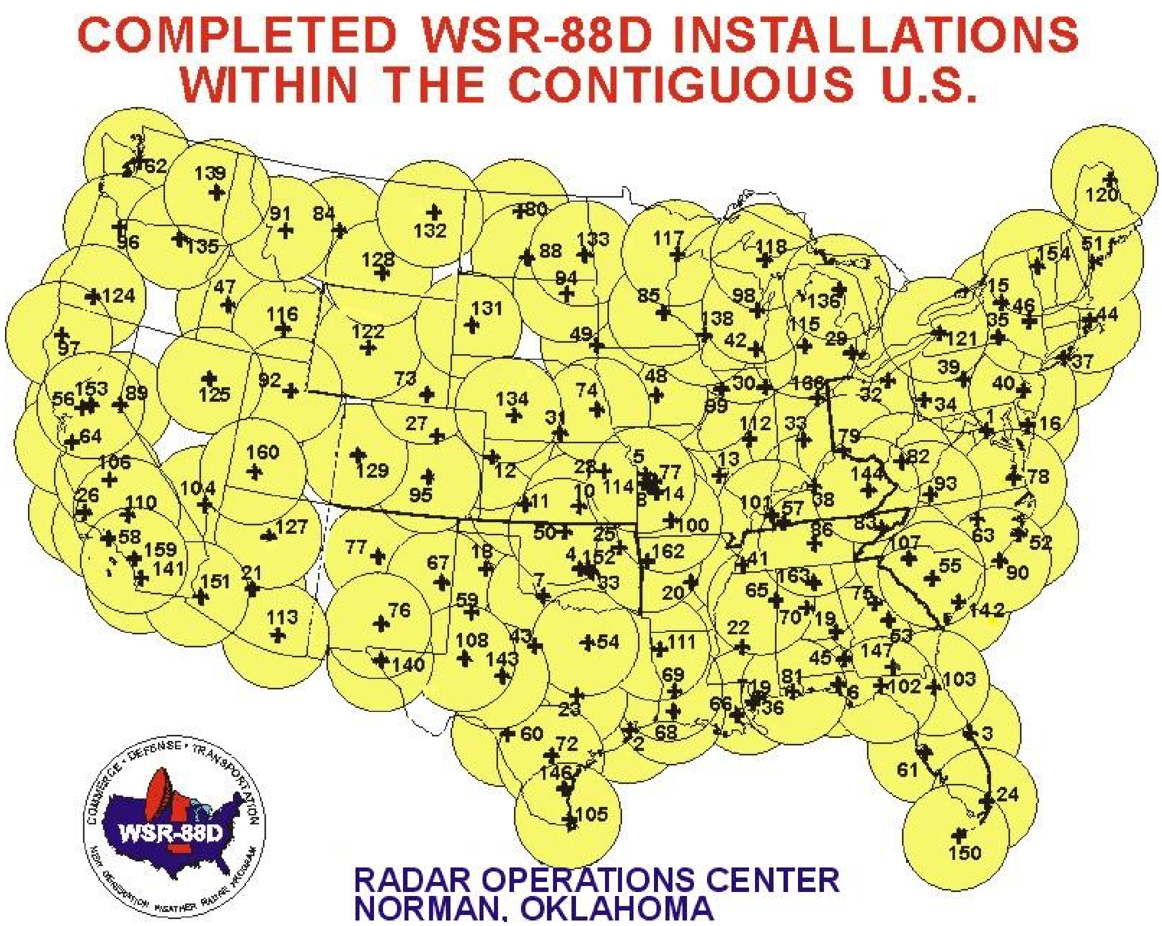

Figure 4.4: National Doppler RADAR Coverage (NOAA: NWS, 2006d)

The RADAR used by the National Weather Service (NWS) is called the WSR-88D, which stands for Weather Surveillance RADAR - 1988 Doppler (the prototype of this RADAR was built in 1988). As its name suggests, the WSR-88D is a Doppler

RADAR, meaning it can detect motions toward or away from the RADAR as well as the location of precipitation areas.

There are 155 WSR-88D Doppler RADAR stations in the nation, including the United States Territory of Guam and the Commonwealth of Puerto Rico, operated by the NWS and the Department of Defense (DOD) as shown in Figure 4.5 below. (NOAA, NWS, 2006b)

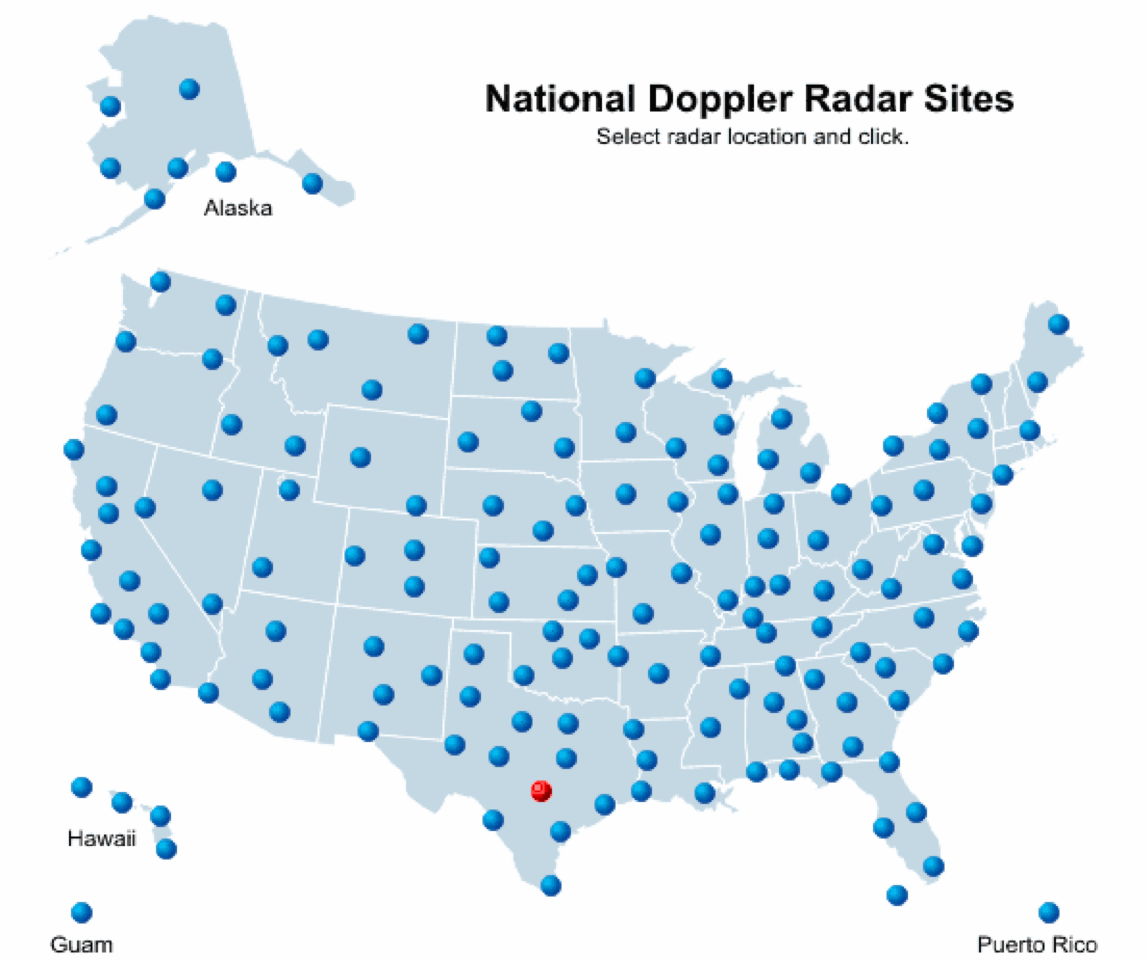

Figure 4.5: National Doppler RADAR Sites (NOAA, NWS, 2006a)

Level II data are collected at each of these RADAR sites. Level II data are the three meteorological base data quantities: reflectivity, mean radial velocity, and spectrum width. From these measurements, computer processing generates numerous meteorological analysis products known as Level III data. (NOAA, NCDC, 2006a)

NEXRAD Level III precipitation data represents the best estimate of rainfall available from the National Weather Service (NWS). One of these Level III products is NEXRAD precipitation data which is collected by the National Weather Service (NWS) and distributed for the entire conterminous United States on a 16 square kilometer grid.

4.1.3 DAYMET

DAYMET stands for DAilY METeorological, and is a model that creates daily surface weather and climatological summaries for the conterminous United States. DAYMET was developed at the University of Montana, Numerical Terradynamic Simulation Group (NTSG), to fulfill the need for fine resolution, daily meteorological and climatological data necessary for plant growth model inputs. It is now maintained by the National Center for Atmospheric Research (NCAR).

Using a digital elevation model and daily observations of minimum and maximum temperatures and precipitation from ground-based gauged meteorological stations, a 25 year (1980 - 2004) daily data set of temperature, precipitation, humidity and radiation has been produced as a continuous surface at a 1 km resolution. (DAYMET, 2006a) An example of the DAYMET national 18-year monthly mean total precipitation for the month of August is shown in Figure 4.6.

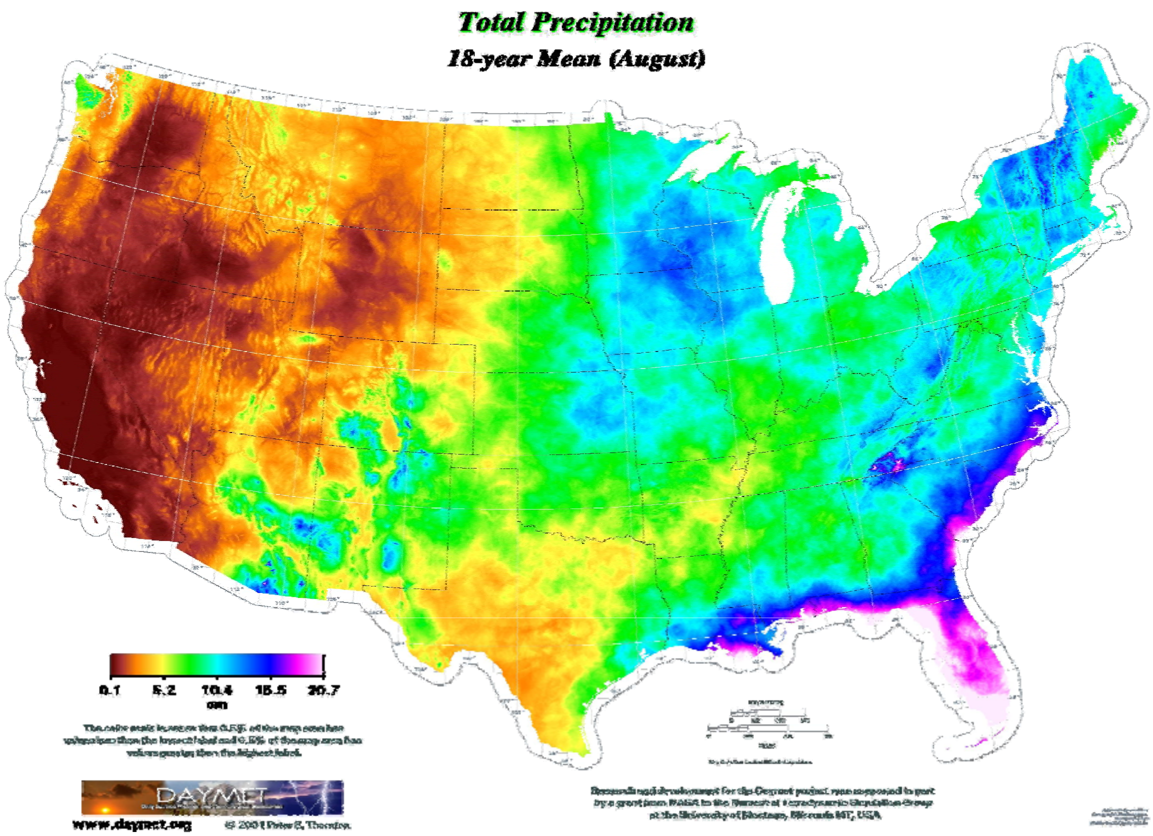

Figure 4.6: National 18-Year Mean Monthly Total Precipitation for August (DAYMET, 2006b)

4.1.4 NARR

NARR stands for North American Regional Reanalysis of climate. NARR was created by the National Center for Environmental Prediction (NCEP) with cooperation from the National Weather Service, the National Oceanic and Atmospheric Administration, and the Department of Commerce. NCEP has published the output of their current weather models that were run using historical observation data, which have interpolated weather related data for a large portion of the North America at a three hour, daily, and monthly average time steps on a 32 kilometer grid. The available weather related data are numerous and include both precipitation and evaporation. NARR data is currently difficult to harvest, and was not considered for this project, but efforts are currently being undertaken that will eliminate this difficulty and make NARR data gathering easier for hydrologic and watershed science analysis in the near future.

4.2 PRECIPITATION DATA SPATIAL COMPARISON

Given the lack of gauging stations across the Sandies and Elm 712 square mile watershed, and the lack of data for over two years of the study period at the one station in the watershed, spatial interpolation of the data from daily stations with available data was attempted.

4.2.1 Initial Precipitation Data Comparison

ArcGIS has multiple tools that calculate rasters files from point data. Of the available GIS methods, the ones chosen for an initial trial include Spline and Inverse Distance Weighted (IDW). The initial interpretation was measured against one day of NEXRAD data that was available for a significant storm which took place on August 27, 2001. The results of this interpolation are shown below. When compared against the NEXRAD image from that day (Figure 4.10) both interpolation methods significantly underestimate the storm. Images of the NCDC gauge data Spline interpolation is shown in Figure 4.7 and the IDW interpolation method is shown in Figure 4.9.

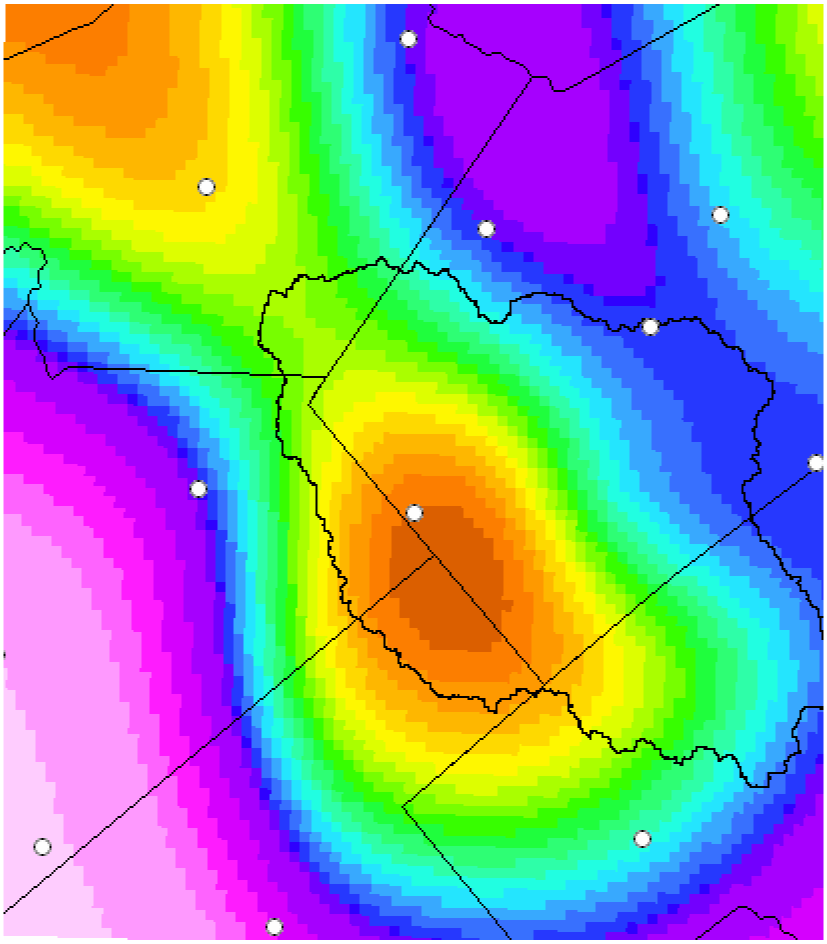

Figure 4.7: NCDC Gauge Spline Interpolation, August 27, 2000

All three of the interpreted storms below are shown at the same color scale, seen in Figure 4.8.

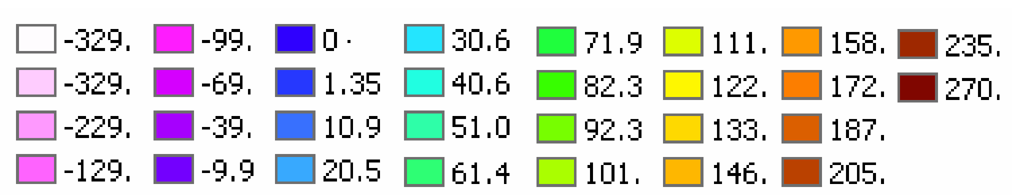

Figure 4.8: Storm Color Scale (hundredth inch)

The Spline interpolation has a nice “rain-like” coverage across the watershed, but has one very large flaw. The areas that are indicated in purple and pink are areas in which the spline method interpolated negative rain. The interpolation by the Inversed Distance Weighted method is shown in Figure 4.9.

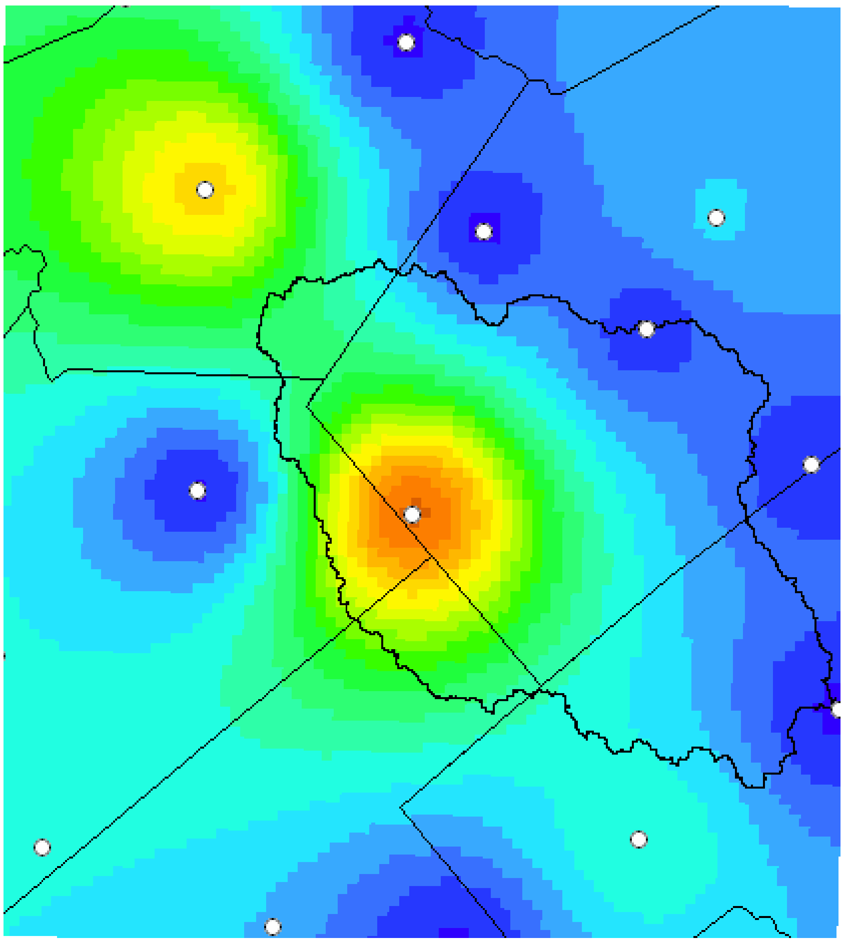

Figure 4.9: NCDC Gauge IDW Interpolation, August 27, 2000

Although the coverage is not quite as “rain-like” as the spline method, there is no negative rain. The Inverse Distance Weighted method was used for all additional gauge interpolations.

The underestimation by the gauges can be explained for a number of reasons, the first being that there are no gauges near the center of the storm cell. This storm event is an example of storms that are common in the semi-arid regions in the summer months.

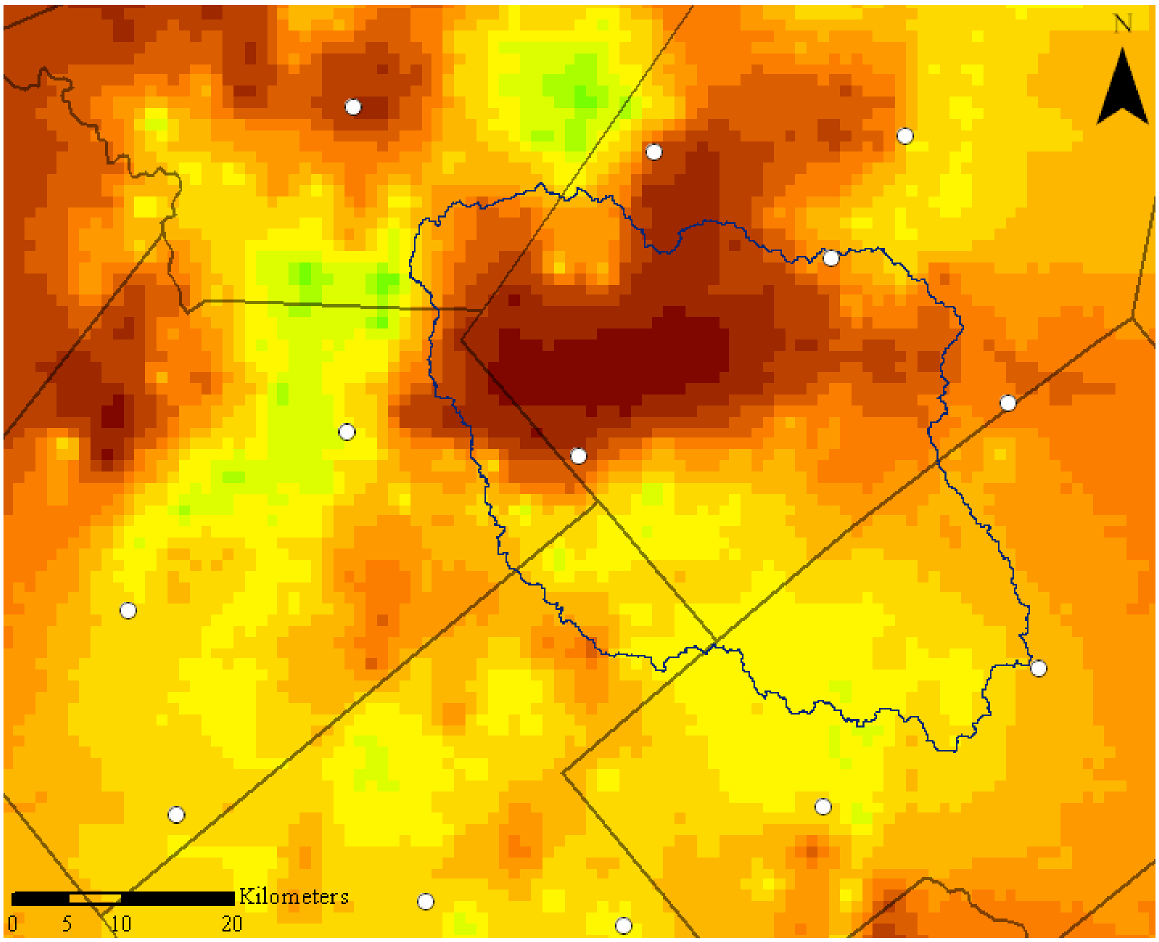

Figure 4.10: NEXRAD Image, August 27, 2000

Intense storm events are dominated by the presence of convective rain cells. (Rebora and Ferraris, 2006) These cells are intense rainfall structures with spatial dimensions from 5 to 10 kilometers that are embedded in regions of more widespread rainfall. The cells tend to last around 30 minutes and produce peak precipitation of 2 to 4 inches/hour. (Austin and Houze, 1972) The storm cell in Figure 4.10 is typical of the above definition. It is 5 km by 20 km with a total precipitation of 3 inches with 2.3 inches of that falling within a one hour time period.

A study of the most severe storms for each month during the study period of 2000 through 2004 was undertaken to examine whether the storm cell phenomena of August 27, 2001 was typical. Stage III NEXRAD data was download from the NOAA, West Gulf River Forecast Center. (NOAA:NWS, 2005b) For more information about this process see section 5.2.1. This data was translated into a database file and evaluated using Microsoft Access.

One set of storms was chosen by using the precipitation from the day in which the maximum value occurred on a single NEXRAD cell for each month of the five year period. This selection method tended to expose the storms containing convective cells. For the remainder of this thesis, this set will be referred to as the Convective Storm Set. Another set of storms was chosen by using the storm in which the maximum value occurred at an NCDC gauge. This technique tended to uncover either widespread intense storms or ones of a frontal system. From this point forward this set will be referred to as the Frontal Storm Set. Table 4.1 lists the storms that were studied. The storms that are in italics are the storms that were selected for study using both methods.

NEXRAD images from each of these storms were compared to the storms as defined by NCDC daily precipitation stations and interpolated by Inverse Distance Weighting and DAYMET. See Appendix A and Appendix B for figures and data associated with the Convective Storm Set and the Frontal Storm Set, respectively.

Table 4.1: Selected Convective and Frontal Storms

	Convective Storms	**Frontal Storms**
January	January 27, 2000	January 8, 2000
February	February 23, 2000	February 21, 2003
March	March 11, 2000	March 15, 2000
April	April 23, 2001	April 8, 2002
May	May 13, 2004	May 20, 2000
June	June 10, 2000	June 30, 2002
July	July 31, 2000	July 15, 2002
August	*August 31, 2001*	*August 31, 2001*
September	September 22, 2001	September 7, 2002
October	October 25, 2003	October 9, 2002
November	*November 17, 2003*	*November 17, 2003*
December	December 12, 2002	December 4, 2002

4.2.2 Precipitation Spatial Evaluation Results

One of the difficulties of spatial interpolation of daily gauge data occurs because each station's precipitation is recorded at a different time. For instance, the Nixon station information is consistently taken at seven in the morning and the New Braunfels Municipal Airport data is taken at midnight. The Cuero 3NW and Cheapside stations present an even more interesting challenge in that the data is taken at these stations at different hours through the five year period. Sometimes the data is taken at eight in the morning and sometimes it is taken at five in the afternoon. Fortunately, the majority of the stations through the five year comparison period took their data at seven in the morning. The New Braunfels Municipal Airport, which consistently took their data at midnight, is far enough away from the watershed that it does not significantly affect the interpolation. Therefore, the NEXRAD data, which is in an hourly format, was aggregated from 7am to 7am to compare accurately with the NCDC gauge data.

The DAYMET interpolation of the daily data makes no attempt at equalizing the recording interval. Therefore, for this area at least, the DAYMET data is also on a 7 am to 7 am time period.

The precipitation rasters were evaluated both visually and using ArcGIS' spatial analyst. All of the storms are shown with the same color scale (See Figure 4.11), so that the intensity of the storms can be seen not just between interpolations for a certain storm but across all of the storms interpolated throughout the study. The storms are measured in hundredth of an inch, which is how they are gauged at NCDC stations.

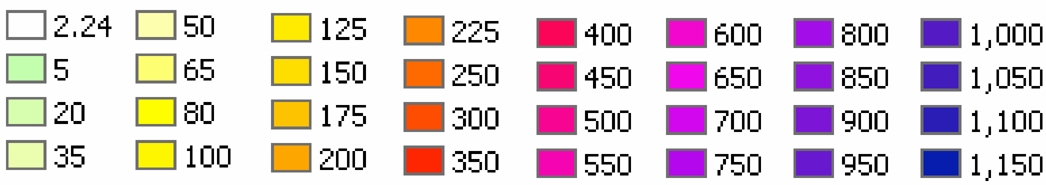

Figure 4.11: Storm Color Scale (hundredth inch)

In the Convective Storm Set, the NCDC gage rainfall interpolation underestimated all but one of the chosen storms. The main difference between the two storm sets was the inability of the gauges to interpret the small and intense convective cells that dominated this series of storms.

An example of this can be seen in the May 13, 2004 storm. The gauged rainfall from this storm was interpolated well over the watershed area in reference to total precipitation. It only had a 12.4% difference between the gage interpolation and NEXRAD over the watershed, but a large and intense storm cell was completely missed just off the watershed boundary as shown in Figure 4.12 and Figure 4.13 below.

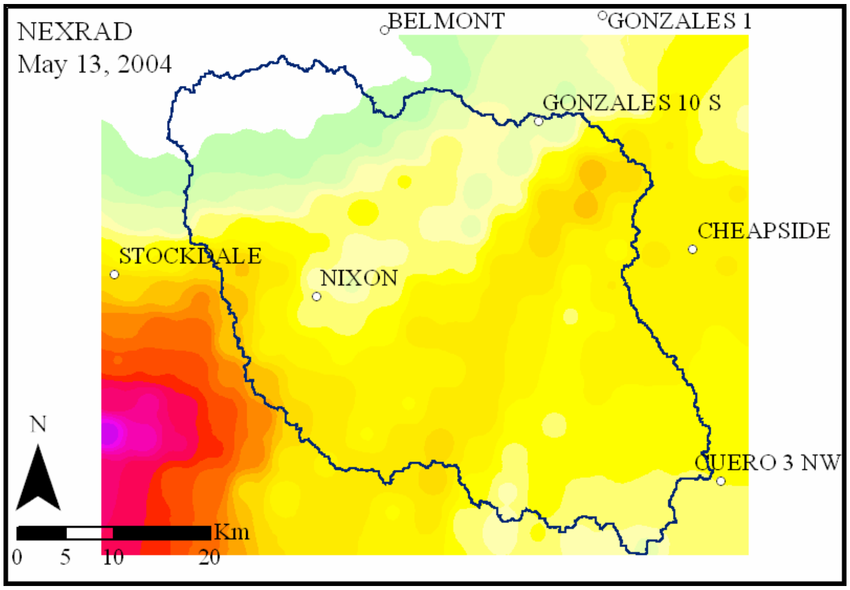

Figure 4.12: NEXRAD May 13, 2004

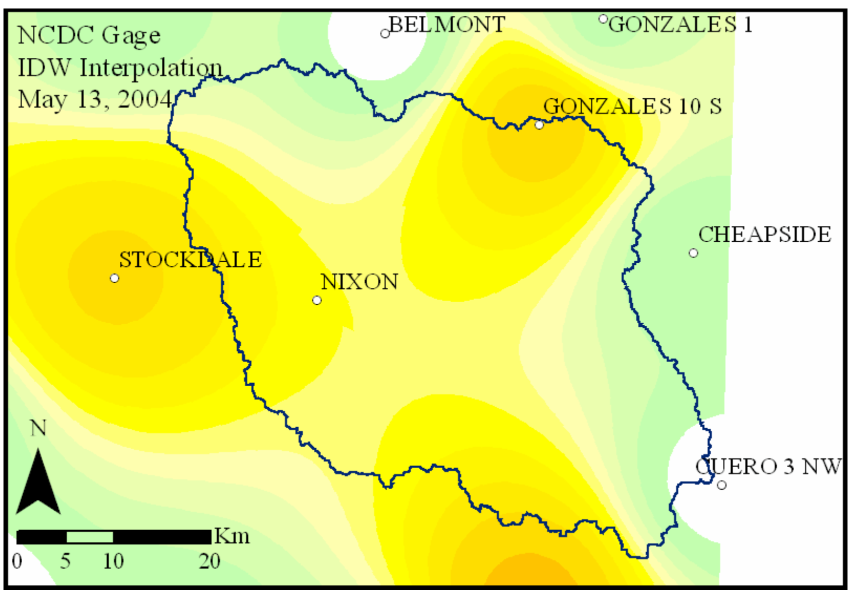

Figure 4.13: NCDC Gauge IDW Interpolation May 13, 2004

There was only one storm in the Convective Storm Set in which the NCDC overestimated the precipitation, November 17, 2003. The total precipitation interpolated from the gauges was 103% greater than that measured by NEXRAD. See the NEXRAD and NCDC Interpolation images of the November 17, 2003 storm in Figure 4.14 and Figure 4.15, respectively, below.

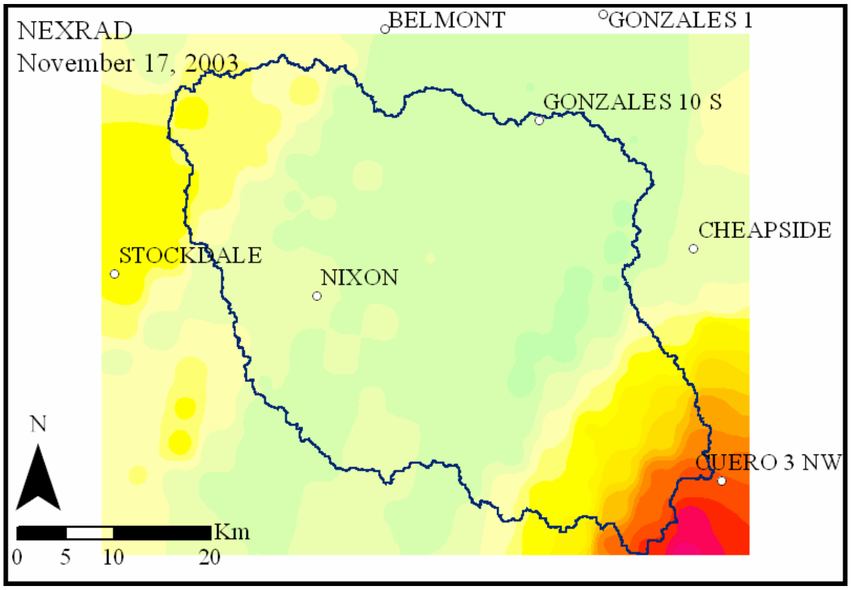

Figure 4.14: NEXRAD November 17, 2003

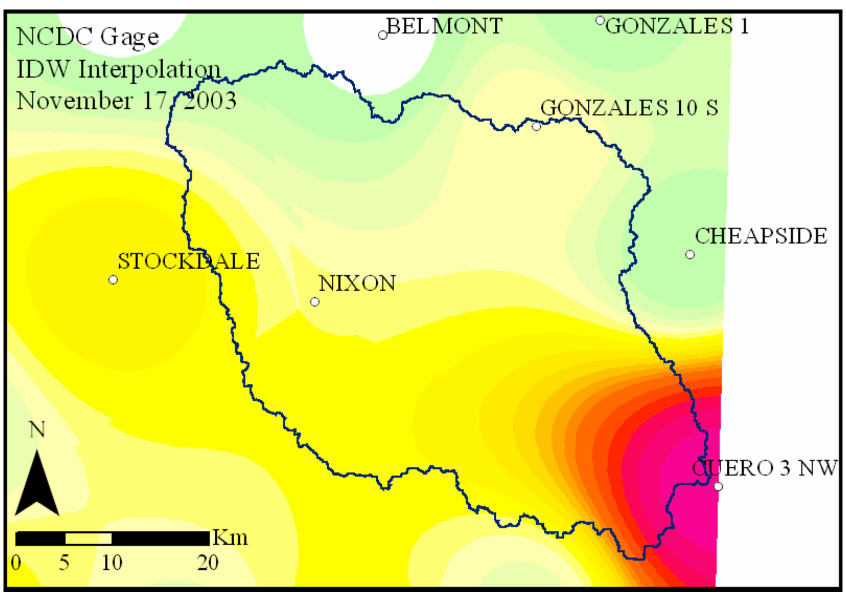

Figure 4.15: NCDC Gauge IDW Interpolation November 17, 2003

During this storm the convective cell was located nearly directly above the Cuero 3NW gaging station. This gauge was interpolated with a greater spatial significance than was measured by NEXRAD and greatly influenced the interpolation between the gauges across the basin.

The storm from October 25, 2003 shows how a significant storm can miss being captured by the NCDC gaging stations. The Nixon station was not in operation at this time and the storm, a significant one, passed above the station through the center of the watershed and had a maximum NEXRAD recorded rainfall near 4.5 inches. The NCDC gauges show no rain, but during this time the USGS flow gauge increases from 5.2 cfs to 15 cfs during the course of a day, which indicates a significant amount of precipitation over the watershed. (See Figure 4.16)

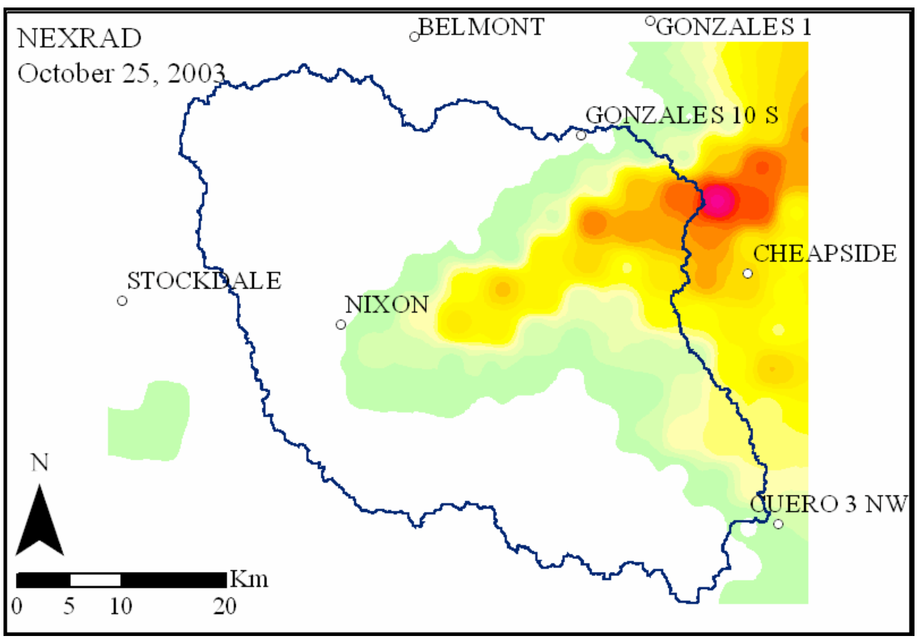

Figure 4.16: NEXRAD October 25, 2003

In the Frontal Storm Set, NCDC overestimated six of the twelve storms evaluated and this overestimation produced an average difference in total precipitation between, the

NCDC interpolated values and the NEXRAD values of 138%. Yet, for four of the twelve storms the difference between NCDC and NEXRAD was below 10% in this batch as opposed to only one of the twelve storms in the Convective Storm Set, and that storm is one that is also included in this set, August 31, 2001.

Visually the Frontal Set storms were very different. This difference was found to be due mainly to the longer precipitation duration of these storms and the differences in recording times between the different NCDC stations.

The most visually obvious example of this difference is shown in Figure 4.17 and Figure 4.18 for the storm from February 21, 2003. This storm had the worst spatial and precipitation total correlation, a 584% difference between the NCDC gage interpolation and NEXRAD data.

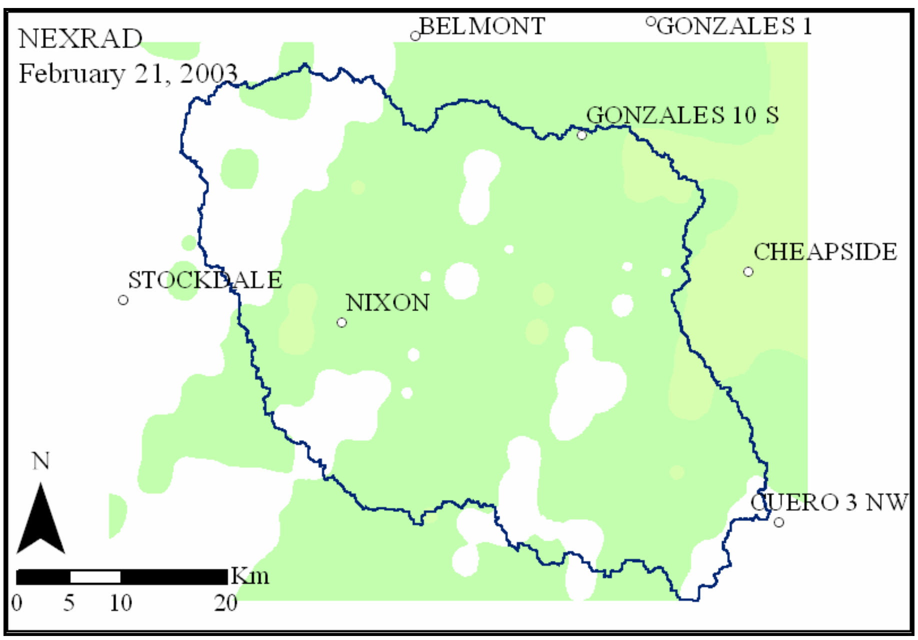

Figure 4.17: NEXRAD February 21, 2003

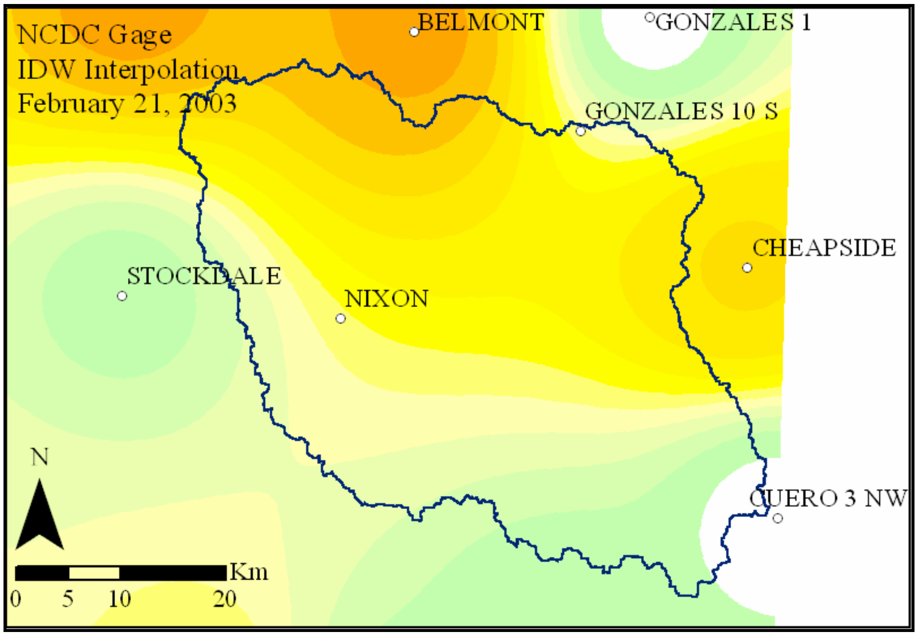

Figure 4.18: NCDC Gauge IDW Interpolation February 21, 2003

These images were so dramatically different that the data was checked multiple times to make certain that the interpolation was correct. NEXRAD data shows that the storm began at 5:00 am on February 20, 2003 and ended at 10:00 am on February 22, 2003. The NEXRAD data showed the storm to peak between 10:00 and 11:00 pm on February 20, 2003. Therefore, most of the body of this storm and its peak should be encapsulated by two days of NCDC gauge data, given the 7am measurement time. Instead it is spread over four days of records as shown in Table 4.2.

An interpolation of the entire storm was created. Taking the whole storm into account greatly reduced the difference in total precipitation between the NCDC interpolation and NEXRAD, but the overall visual comparison is still not good. This is most likely due in part to the data missing at two stations, Gonzales 10 SW and Nixon. See Figure 4.19 and Figure 4.20 below for the total storm interpolations.

Table 4.2: NCDC Data for February 21, 2003 Storm

	Precipitation (h.i.)				
	2/19/2003	**2/20/2003**	**2/21/2003**	**2/22/2003**	**Sum**
BELMONT	0	0	206	0	206
CHEAPSIDE	0	10	152	15	177
CUERO 3 NW	0	0	0	0	0
FALLS CITY 4 WSW	0	16	60	0	76
FLORESVILLE	0	92	35	0	127
GONZALES 1	0	0	0	0	0
KARNES CITY	0	47	90	9	146
KINGSBURY	0	172	235	21	428
NEW BRAUNFELS MAP	57	170	21	0	248
RUNGE	26	97	0	0	123
SEGUIN 1 SSW	0	60	210	58	328
STOCKDALE	15	102	14	0	131
YORKTOWN	19	82	6	0	107

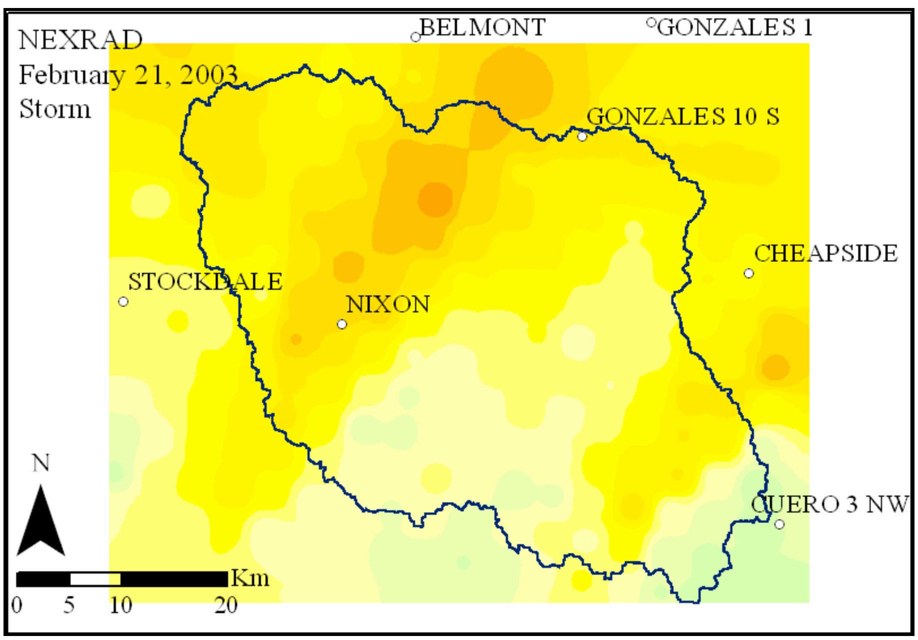

Figure 4.19: NEXRAD 2/19/2003 thru 2/22/2003

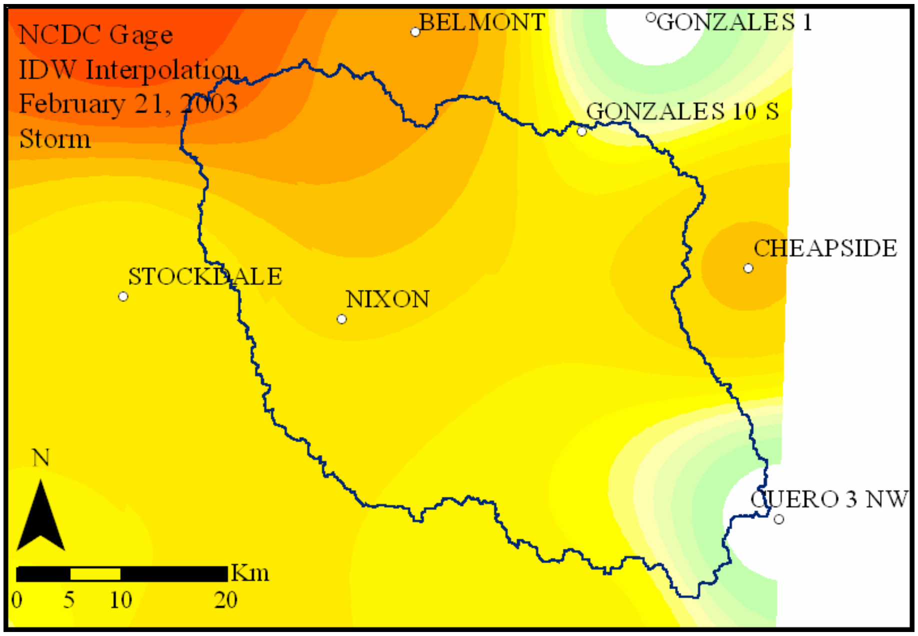

Figure 4.20: NCDC Gauge IDW Interpolation 2/19/2003 thru 2/22/2003

Given the very significant increase in flow at the gauge from 219 cfs to 2650 cfs from February 20, 2003 to February 23, 2003 it is reasonable to guess that NEXRAD underestimated this storm rather than the NCDC gauges overestimating it.

The entire storm is not nearly as undervalued as the one day of rain in February that was initially evaluated. NEXRAD still underestimates the storm by 35.8%; see Table 4.3 below, but the range, mean, and standard deviation are much closer together.

Table 4.3: Spatial Analysis of Precipitation Methods over Sandies & Elm Watershed

Date	Type	Total (in)	Min (in)	Max (in)	Mean (in)	Std. Dev. (in)
February 21, 2003 Storm	NCDC	256,309.00	0.00	2.80	1.39	0.49
	NEXRAD	188,752.00	0.24	2.18	1.02	0.40
	Difference	**-35.8%**	**0.24**	**-0.62**	**-0.37**	**-0.09**

Another storm in which a visual inspection of the interpolations gave pause was the storm from March 14, 2000. Comparison of Figure 4.21 and Figure 4.22 shows a large discrepancy between the two methods. The visual inconsistency was so great between the NEXRAD and NCDC gauge interpolation that the entire storm was interpolated and checked.

The NEXRAD data indicates that the rain from this storm fell between 6:00 pm on March 14, 2000 and 6:00 am on March 15, 2000. Therefore, the storm should be encompassed by one day of NCDC daily gauge data (see Table 4.4 for NCDC precipitation data) if the measurements were taken, as indicated, at 7:00 am. Instead, the storm appears to be spread over two days, March 14 and 15. The interpolation of the entire storm is shown in Figure 4.23 and Figure 4.24.

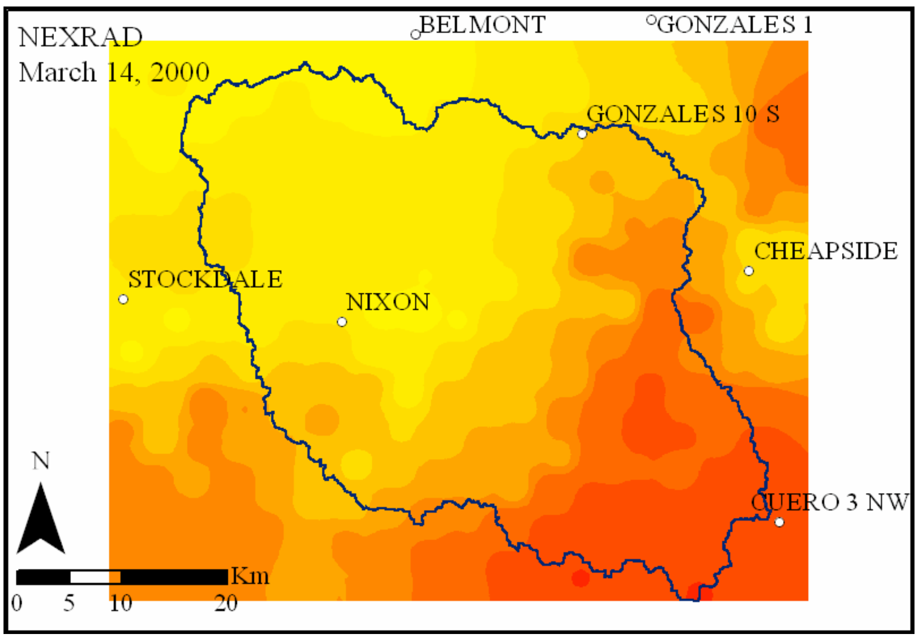

Figure 4.21: NEXRAD March 14, 2000

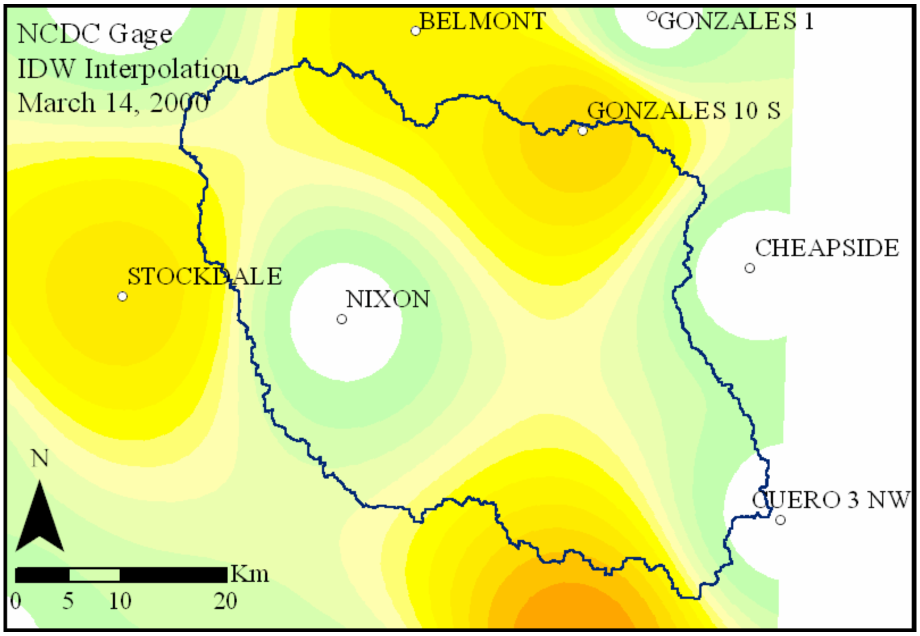

Figure 4.22: NCDC Gauge IDW Interpolation March 14, 2000

Table 4.4: NCDC Data for March 14, 2000 Storm

	Precipitation (h.i.)		
	3/14/2000	**3/15/2000**	**Sum**
BELMONT	110	0	110
CHEAPSIDE	0	192	192
CUERO 3 NW	0	201	201
FALLS CITY 4 WSW	0	0	0
FLORESVILLE	22	134	156
GONZALES 1	0	156	156
GONZALES 10 SW	165	0	165
KARNES CITY	17	282	299
NIXON	0	144	144
RUNGE	0	139	139
SEGUIN 1 SSW	0	80	80
STOCKDALE	135	0	135
YORKTOWN	215	0	215

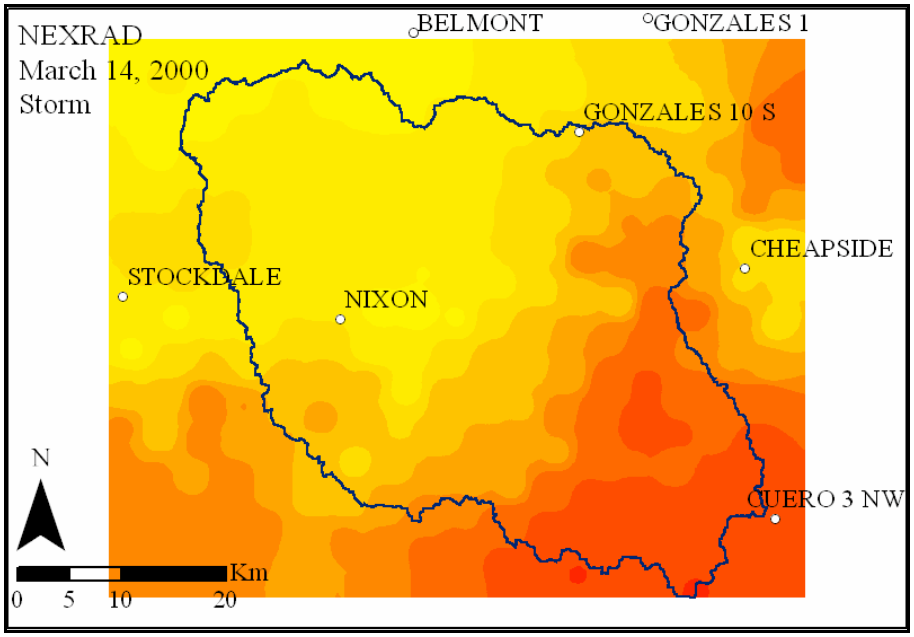

Figure 4.23: NEXRAD 3/14/2000 thru 3/15/2000

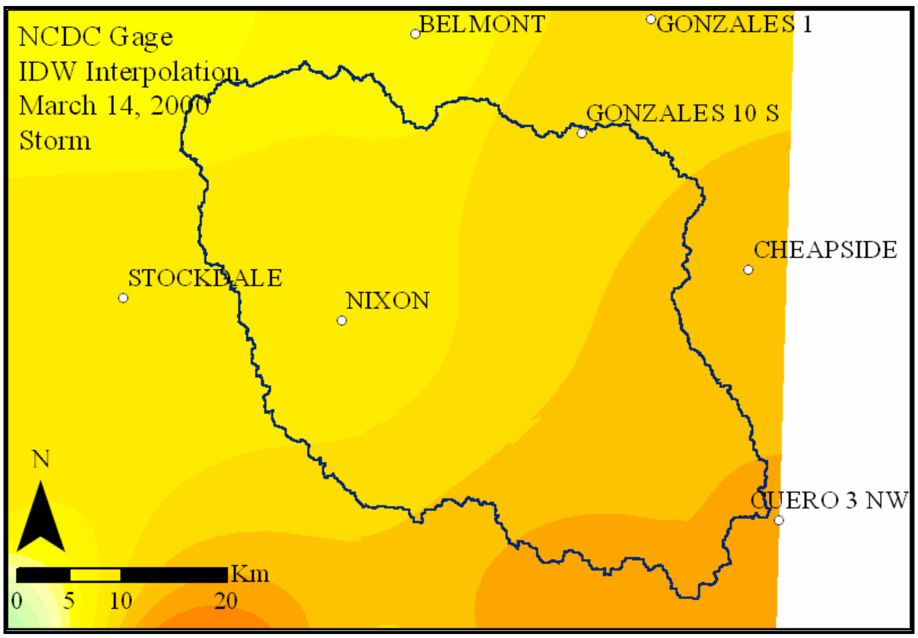

Figure 4.24: NCDC Gauge IDW Interpolation 3/14/2000 thru 3/15/2000

The precipitation totals from the two methods compare more reasonably for this storm. Only a 17.2% difference was detected between the two methods as shown in Table 4.5.

Table 4.5: Spatial Analysis of Precipitation Methods over Sandies & Elm Watershed

Date	Type	Total (in)	Min (in)	Max (in)	Mean (in)	Std. Dev. (in)
March 14, 2000 Storm	NCDC	296,079.00	1.00	2.11	1.61	0.24
	NEXRAD	357,625.00	1.07	3.58	1.94	0.63
	Difference	**17.2%**	**0.07**	**1.47**	**0.33**	**0.39**

One of the very best interpolations according to the precipitation totals, with only 1% difference between the NCDC interpolation and NEXRAD, was the interpolation of the storm from June 30, 2002. As shown in Figure 4.25 and Figure 4.26, the overall precipitation pattern was well formed over the watershed, but the NCDC did interpolate the northwest corner with more rain than was estimated from the NEXRAD data.

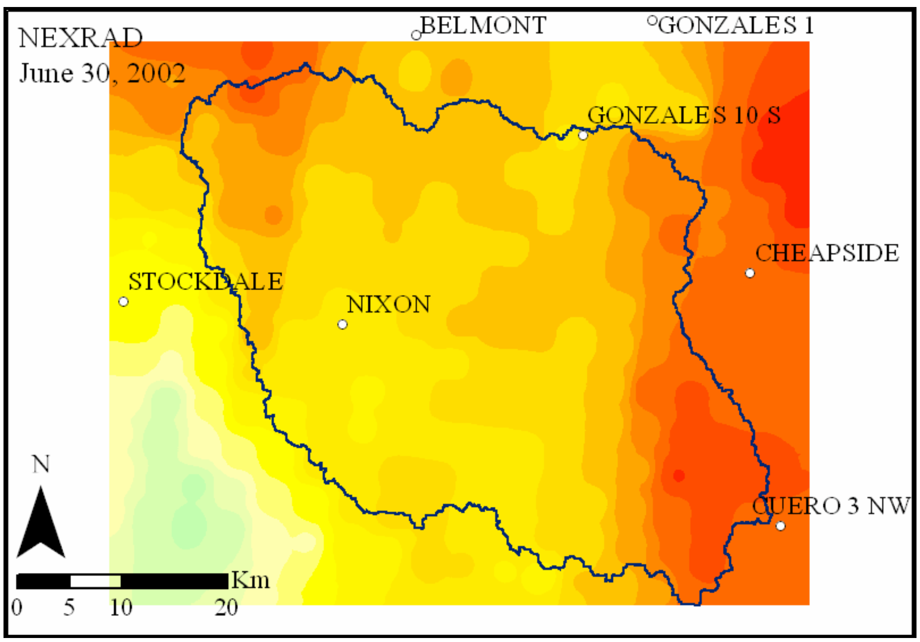

Figure 4.25: NEXRAD June 30, 2002

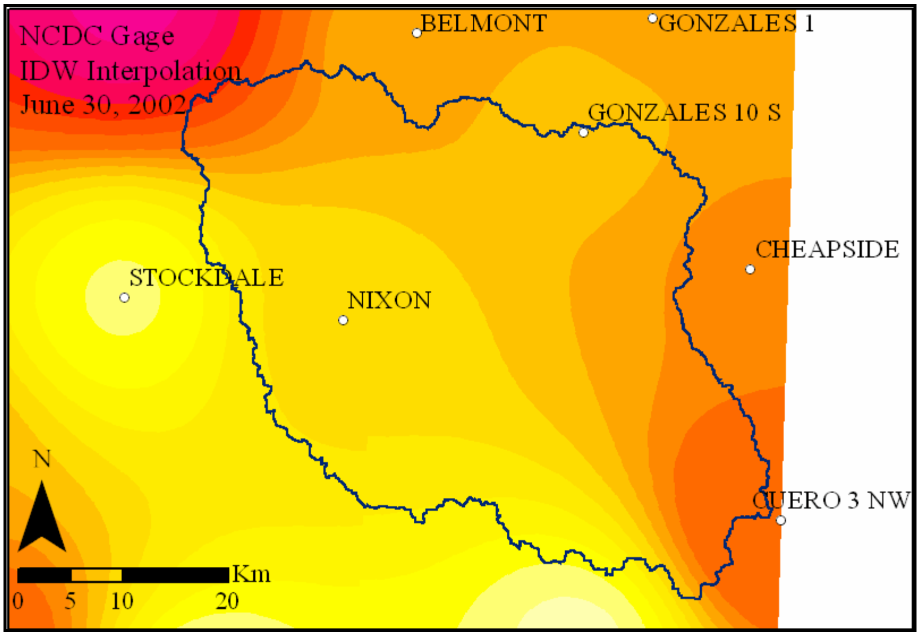

Figure 4.26: NCDC Gauge IDW Interpolation June 30, 2002

4.2.3 Precipitation Spatial Evaluation Summary

Overall the NCDC stations underestimated the precipitation measured by NEXRAD 70% of the time. When the total precipitation was underestimated it was underestimated by an average of 43.2%. When the total precipitation was overestimated it was overestimated by an average of 138%. The overall average total precipitation estimation differed by 71.4% for the two methods.

On average each storm studied had between 1 and 3 convective cells measuring between 5 and 10 kilometers. The total precipitation assessment of the gauge interpolation versus NEXRAD shows that the gauges did a good job (less than 30% difference) of defining the overall precipitation in 7 out of 22 storms analyzed. Table 4.6 and Table 4.7 summarize the GIS spatial analysis of the NCDC Interpolation and NEXRAD precipitation over the Sandies and Elm watershed.

Table 4.6: Convective Storm Set Spatial Analysis over the Sandies & Elm Watershed

Date	Type	Total (in)	Min (in)	Max (in)	Mean (in)	Std. Dev. (in)
January 27, 2000	NCDC	64,788.80	0.12	0.76	0.35	0.17
	NEXRAD	94,459.80	0.11	1.35	0.51	0.25
	Difference	**31.4%**	**-0.01**	**0.59**	**0.16**	**0.08**
February 23, 2000	NCDC	189,615.00	0.00	2.16	1.03	0.44
	NEXRAD	308,198.00	0.28	2.98	1.67	0.59
	Difference	**38.5%**	**0.28**	**0.82**	**0.64**	**0.15**
March 11, 2000	NCDC	9,695.44	0.00	0.18	0.05	0.04
	NEXRAD	126,867.00	0.00	5.20	0.69	1.14
	Difference	**92.4%**	**0.00**	**5.02**	**0.64**	**1.10**
April 23, 2001	NCDC	44,991.70	0.00	2.04	0.24	0.24
	NEXRAD	242,869.00	0.15	3.29	1.32	0.67
	Difference	**81.5%**	**0.15**	**1.25**	**1.08**	**0.43**
May 13, 2004	NCDC	139,660.00	0.00	1.64	0.76	0.35
	NEXRAD	159,472.00	0.00	2.16	0.87	0.44
	Difference	**12.4%**	**0.00**	**0.52**	**0.11**	**0.09**
June 10, 2000	NCDC	286,549.00	0.58	2.85	1.56	0.47
	NEXRAD	406,569.00	0.88	5.50	2.21	0.93
	Difference	**29.5%**	**0.30**	**2.65**	**0.65**	**0.46**
July 31, 2000	NCDC	2,554.15	0.00	0.08	0.01	0.02
	NEXRAD	59,559.30	0.00	2.92	0.32	0.39
	Difference	**95.7%**	**0.00**	**2.84**	**0.31**	**0.37**
August 31, 2001	NCDC	739,440.00	0.32	8.30	4.02	1.77
	NEXRAD	772,034.00	0.77	9.17	4.19	2.14
	Difference	**4.2%**	**0.45**	**0.87**	**0.17**	**0.37**
September 22, 2001	NCDC	38,421.20	0.02	0.75	0.21	0.17
	NEXRAD	68,008.50	0.00	1.72	0.37	0.32
	Difference	**43.5%**	**-0.02**	**0.97**	**0.16**	**0.15**
October 25, 2003	NCDC	0.00	0.00	0.00	0.00	0.00
	NEXRAD	46,978.50	0.00	4.47	0.25	0.50
	Difference	**100.0%**	**0.00**	**4.47**	**0.25**	**0.50**
November 17, 2003	NCDC	194,011.00	0.03	5.30	1.05	1.04
	NEXRAD	95,273.60	0.13	4.00	0.52	0.50
	Difference	**-103.6%**	**0.10**	**-1.30**	**-0.53**	**-0.54**
December 12, 2002	NCDC	87,005.60	0.00	1.80	0.47	0.40
	NEXRAD	178,093.00	0.26	3.71	0.97	0.62
	Difference	**51.1%**	**0.26**	**1.91**	**0.50**	**0.22**

Table 4.7: Frontal Storm Set Spatial Analysis over the Sandies & Elm Watershed

Date	Type	Total (in)	Min (in)	Max (in)	Mean (in)	Std. Dev. (in)
January 7, 2000	NCDC	274,628.00	0.63	3.32	1.49	0.60
	NEXRAD	152,924.00	0.36	1.85	0.83	0.20
	Difference	**-79.6%**	**-0.27**	**-1.47**	**-0.66**	**-0.40**
February 21, 2003	NCDC	119,736.00	0.00	1.98	0.65	0.42
	NEXRAD	17,497.20	0.00	0.34	0.09	0.60
	Difference	**-584.3%**	**0.00**	**-1.64**	**-0.56**	**0.18**
March 14, 2000	NCDC	111,738.00	0.00	1.86	0.61	0.42
	NEXRAD	357,625.00	1.07	3.58	1.94	0.63
	Difference	**68.8%**	**1.07**	**1.72**	**1.33**	**0.21**
April 8, 2002	NCDC	595,932.00	1.10	5.08	3.23	1.02
	NEXRAD	557,688.00	0.47	5.56	3.03	1.30
	Difference	**-6.9%**	**-0.63**	**0.48**	**-0.20**	**0.28**
May 20, 2000	NCDC	190,395.00	0.00	4.20	1.03	0.78
	NEXRAD	233,947.00	0.17	3.26	1.27	0.67
	Difference	**18.6%**	**0.17**	**-0.94**	**0.24**	**-0.11**
June 30, 2002	NCDC	346,926.00	0.80	3.74	1.88	0.41
	NEXRAD	350,552.00	1.00	3.51	1.90	0.49
	Difference	**1.0%**	**0.20**	**-0.23**	**0.02**	**0.08**
July 15, 2002	NCDC	211,415.00	0.71	1.90	1.15	0.25
	NEXRAD	610,469.00	1.67	4.71	3.31	0.59
	Difference	**65.4%**	**0.96**	**2.81**	**2.16**	**0.34**
August 31, 2001	NCDC	739,440.00	0.32	8.30	4.02	1.77
	NEXRAD	772,034.00	0.77	9.17	4.19	2.14
	Difference	**4.2%**	**0.45**	**0.87**	**0.17**	**0.37**
September 7, 2002	NCDC	431,025.00	1.27	4.98	2.36	0.64
	NEXRAD	290,018.00	0.03	4.23	1.57	1.12
	Difference	**-48.6%**	**-1.24**	**-0.75**	**-0.79**	**0.48**
October 9, 2002	NCDC	314,660.00	0.22	6.29	1.71	0.91
	NEXRAD	303,712.00	0.63	4.49	1.65	0.69
	Difference	**-3.6%**	**0.41**	**-1.80**	**-0.06**	**-0.22**
November 17, 2003	NCDC	194,011.00	0.03	5.30	1.05	1.04
	NEXRAD	95,273.60	0.13	4.00	0.52	0.50
	Difference	**-103.6%**	**0.10**	**-1.30**	**-0.53**	**-0.54**
December 4, 2002	NCDC	157,014.00	0.00	2.45	0.85	0.48
	NEXRAD	278,305.00	0.85	2.29	1.51	0.37
	Difference	**43.6%**	**0.85**	**-0.16**	**0.66**	**-0.11**

4.3 PRECIPITATION STUDY RESULTS

There are many regions of the country where NCDC gauges are able to accurately represent the precipitation pattern over a watershed. This region of south central Texas is not one of them. The area is afflicted by storm systems which have multiple convective cells with high intensity precipitation. The NCDC gauges are very far apart and not consistent in their recording patterns and availability. This creates a high degree of unreliability in the precipitation interpolation data. NEXRAD is available on an hourly basis where all but one NCDC gauge only had data on a daily time step. For all of these reasons NEXRAD data was chosen for use as the precipitation forcing data in the HSPF model of the Sandies and Elm watershed.

Images of NEXRAD, gauge interpolation, and DAYMET for each of the studied storms are included for the Convective Storm Set in Appendix A and for the Frontal Storm Set in Appendix B.

Chapter 5 Model Development

5.1 GIS TO HSPF OVERVIEW

The ArcGIS HSPF Preprocessing methodology was designed to facilitate the development of an HSPF model in the ESRI ArcGIS environment. This methodology emulates the EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) HPSF Preprocessing methodology, but implements it in the ArcGIS environment. The only major conceptual difference between the two methods concerns the effort to maintain a geospatial description of elements from GIS data in the HSPF model. Though spatial information is not explicitly stored in the HSPF model input file, each model element simulated by HSPF represents some spatial location in the real world. In order to facilitate the transfer of information to and from the GIS environment, a spatial representation of the areas of land simulated by HSPF is created and must be maintained. The following are the major tasks accomplished by the ArcGIS HSPF Preprocessing methodology and utilities in developing a new HSFP model.

1) Drainage areas boundaries and river networks are defined
2) Land Segments are defined
3) Other physically-based attributes are calculated
4) HSPF input files are created, which include
    a) The user control input (.uci) file
    b) Three intermediate files
        i) Reaches (.rch) file
        ii) Channel geometry (.ptf) file
        iii) Watershed delineation (.wsd) file
    c) Forcing data input (.wdm) file

Table 5.1 displays an overview of the processes and tools used in the ArcGIS to HSPF Preprocessing methodology.

Table 5.1: Overview of ArcGIS, HSPF, and Timeseries Preprocessing Methodologies (Johnson, 2005)

	Tasks required to create new HSPF model	***Arc Hydro Data and Tools***	***ArcGIS Tools***	***WinHSPF/GenScn/ WdmUtil***
ArcGIS HSPF Preprocessing methodology	Define drainage area boundaries and river network	Arc Hydro Catchment/ DrainageLine data		
	Calculate Physically-based parameters		Standard ArcGIS tools*	
	Define Model Elements to be simulated		Standard ArcGIS tools*	
	Extract data from GIS to intermediate text files		Custom ArcGIS tools**	
	Create new .uci file from intermediate text files			WinHSPF 'Create Project' tool
ArcGIS Timeseries Preprocessing methodology	Write timeseries data to .wdm file	TimeSeries structure	Custom ArcGIS tools**	WdmUtil/GenScn programming libraries
	Update .uci file to read from new timeseries datasets		Custom ArcGIS tools**	WdmUtil/GenScn programming libraries

**Though standard ArcGIS tools are available for these tasks, ModelBuilder models were created to streamline the process.*

***Custom ArcGIS Geoprocessing functions were created to perform these tasks.*

For more information about the ArcGIS to HSPF Preprocessing methodology see *ArcGIS and HSPF Model Development*. (Johnson, 2005)

5.2 DATA COLLECTION

The most important activity when creating an HSPF model is to characterize the watershed accurately. GIS based data is widely used both to estimate physically-based parameters and to define areas of similar hydrologic character. (Singh and Woolhiser, 2002) GIS data is available from many federal, state, and local government agencies such as the United States Geological Survey (USGS), the Environmental Protection Agency (EPA), and the Texas Commission for Environmental Quality (TCEQ). These data sources define many watershed characteristics such as, stream networks, topography, land use / land cover, geology, and soils. More recently, spatially defined climatic data has also become available for use in a GIS environment. The ArcGIS HSPF Preprocessing methodology, which is summarized in the previous section, was designed to incorporate spatially defined weather data, such as NEXRAD precipitation into an HSPF model.

5.2.1 Precipitation

NEXRAD spatial precipitation files were downloaded for the area around the Sandies and Elm watershed from the West Gulf River Forecast Center (WGRFC) website. (NOAA: NWS, 2005b) The extent of NEXRAD data for the Sandies and Elm watershed is shown in See Figure 5.1.

The WGRFC area is defined by the watershed areas from rivers draining into the Gulf of Mexico. This area includes the majority of Texas, and parts of New Mexico, Colorado, and Mexico. Figure 5.2 displays the area of interest for the West Gulf River Forecast Center.

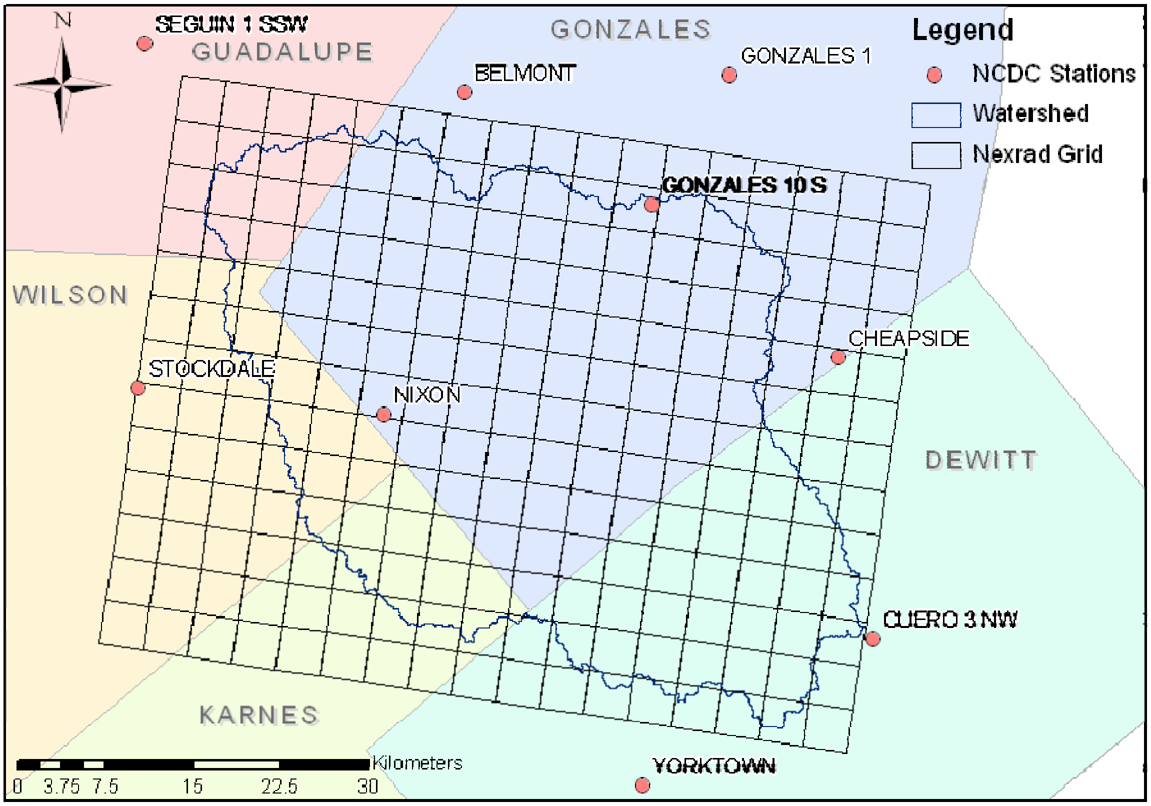

Figure 5.1: NEXRAD Cell Coverage of the Sandies & Elm Watershed

The incorporation of NEXRAD precipitation data into the ArcGIS and subsequently the HSPF environment is a complex and tedious task. NEXRAD data from the WGRFC site is organized in the Hydrologic Rainfall Analysis Project (HRAP) coordinate system, which is a polar stereographic (spherical earth datum) projection. In comparison, most geospatial data are in geodetic datum (ellipsoidal earth) coordinate system. The precipitation datasets are in nested compressed binary format files (XMRG). For one year of data there are twelve compressed binary monthly files, 672 to 744 uncompressed ASCII hourly files. (NOAA: NWS, 2006b; Xie, *et al.*, 2003)

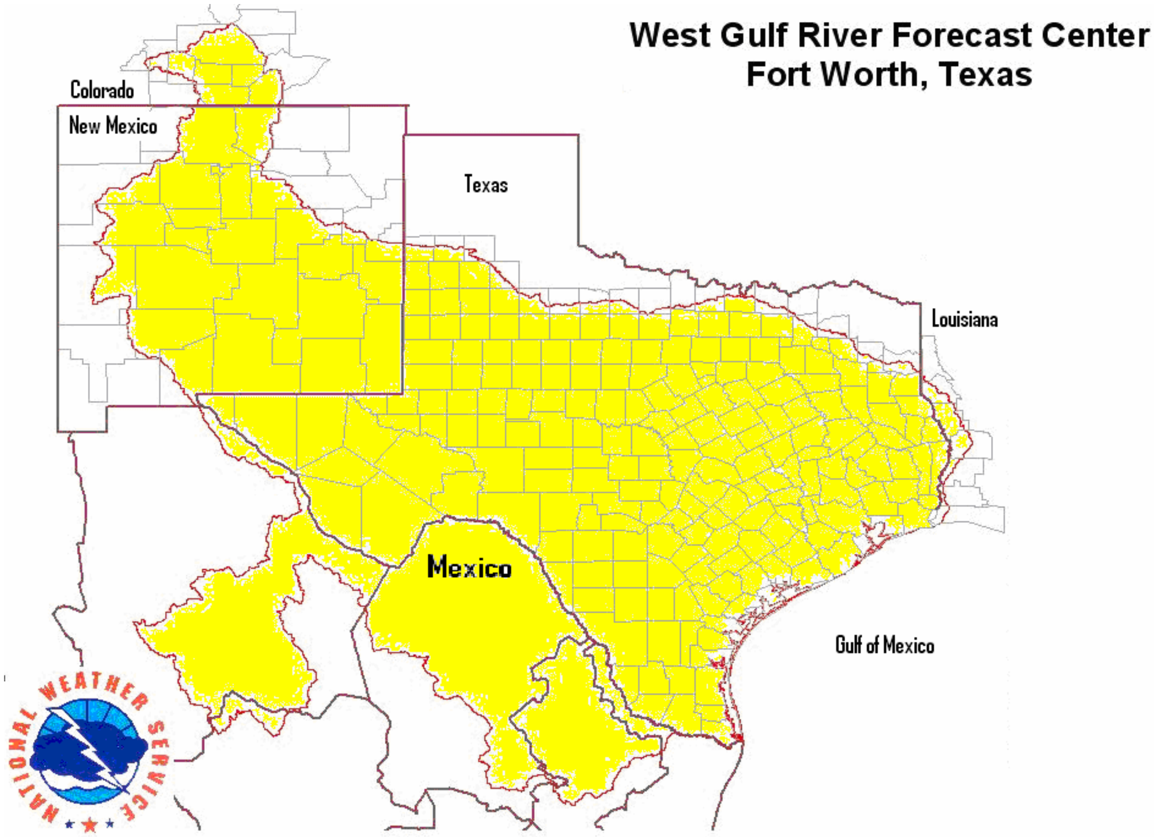

Figure 5.2: West Gulf River Forecast Center Area of Interest (NOAA: NWS, 2005b)

NEXRAD precipitation data is stored in a format very different from the .wdm file format required for HSPF modeling. ArcGIS and HSPF Model Development, Appendix B (Johnson, 2005) describes the process used to extract NEXRAD data from its native binary format and write it into the Arc Hydro timeseries format. GIS tools are then used to transfer the precipitation data from Arc Hydro timeseries format into the .wdm file format required by HSPF.

A GIS representation of the HSPF concept of the meteorological segments is then used to organize and prepare input time series. Figure 5.3, below, illustrates the overall concept of the ArcGIS Timeseries Preprocessing methodology. At the heart of the ArcGIS Timeseries Preprocessing system is the GIS MetSegment feature class. It contains information that joins the associated features of the Arc Hydro timeseries data to the HSPF model files. (Johnson, 2005) This connection is important given the spatial relationship that is required to accurately transfer data between the GIS and HSPF environments.

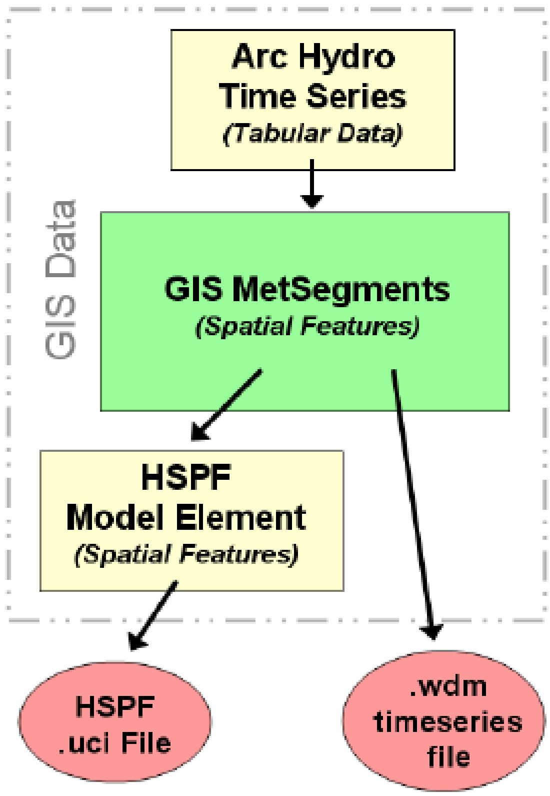

Figure 5.3: Schematic Overview of ArcGIS Timeseries Preprocessing Methodology (Johnson, 2005)

5.2.2 Evaporation

A search of NCDC evaporation stations in the five county area produced no results. Extending the radius, five evaporation stations, shown in Figure 5.4, were found in the nearby area. The evaporation data from these sites were incomplete; therefore an average of the available data was taken and put into one evaporation timeseries for the entire watershed. Since these stations were all at large reservoirs a pan evaporation factor of 0.70 was applied to the evaporation timeseries in the HSPF model.

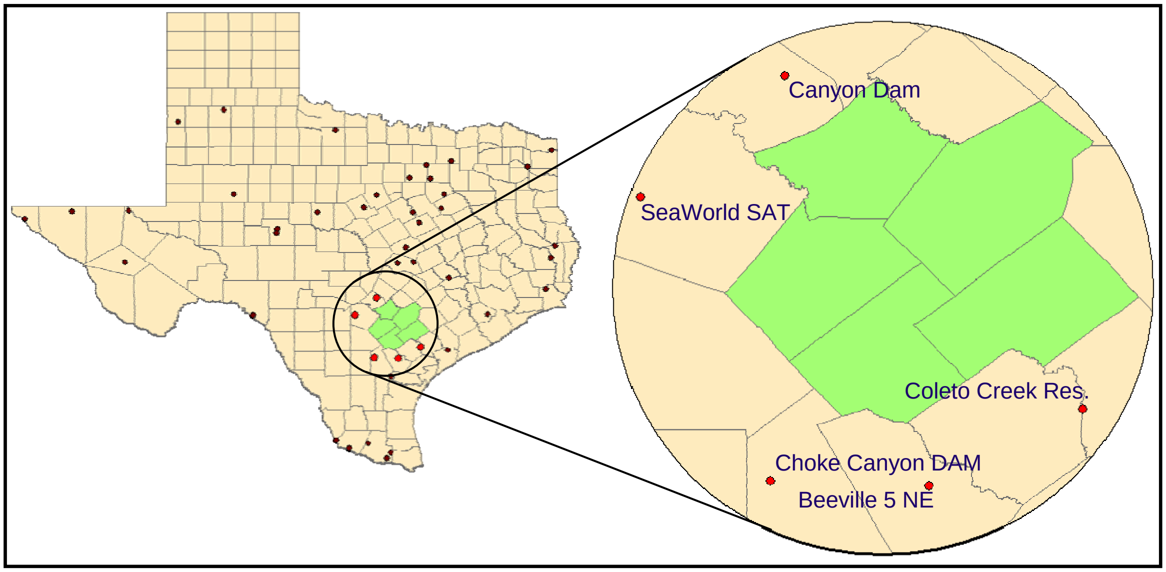

Figure 5.4: NCDC Evaporation Stations

5.2.3 Land Use / Land Cover

The 2000 land use / land cover data set is not currently available for the Sandies and Elm watershed. Therefore, digital raster images of the 1992 land use / land cover were downloaded from the United States Geological Survey (USGS), Seamless site. (See Figure 5.5) (USGS: Seamless, 2005) The use of this data is not considered erroneous because the watershed is not a region of rapid growth or change.

The National Land Cover Data 1992 (NLCD 92) is a 21-category land cover classification scheme that has been applied consistently over the conterminous United States. The NLCD 92 classification is provided as raster data with a spatial resolution of 30 meters. The data is expressed in geographic coordinates (latitude/longitude), and it is referenced to the North American Datum of 1983 (NAD83). (USGS: Seamless, 2006a)

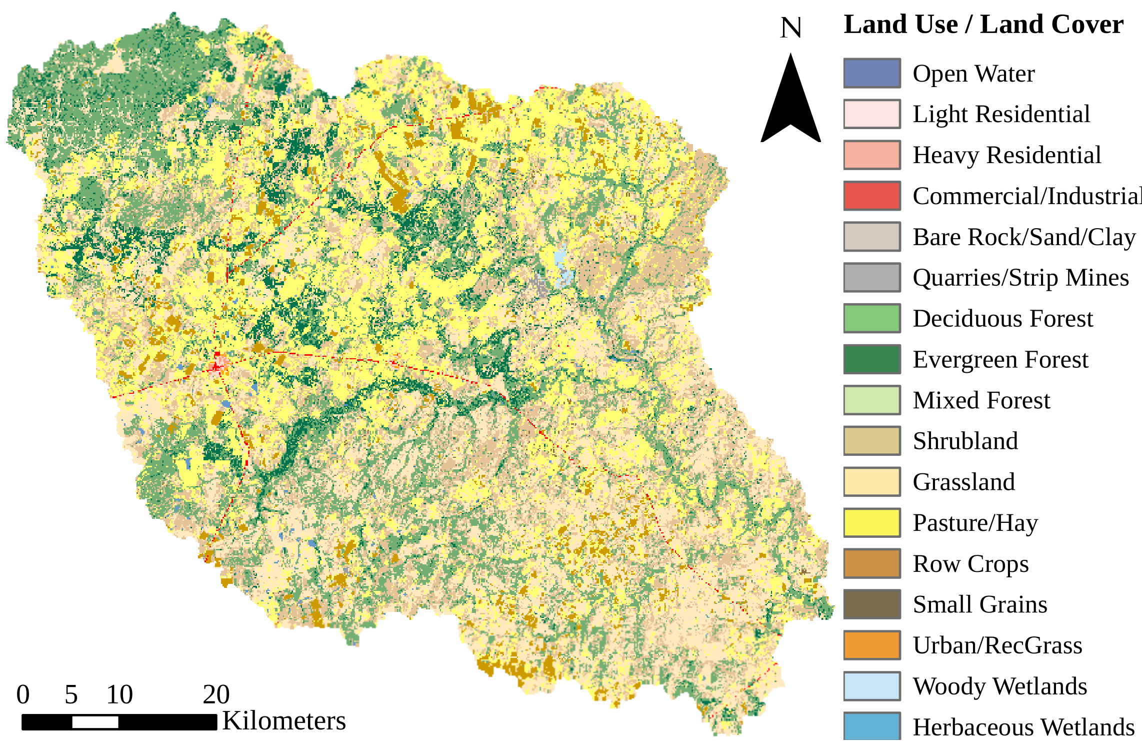

Figure 5.5: Land Use / Land Cover Data (USGS: Seamless, 2006a)

5.2.4 Streams

The high-resolution streams from the national hydrography dataset were downloaded from the NHD website as seen in Figure 5.6. (USGS: NHD, 2005)

The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. The high-resolution NHD, was developed at a 1:24,000 to a 1:12,000 scale. This increase in resolution added a good amount of detail from the original 1:100,000-scale NHD. (USGS: NHD, 2005)

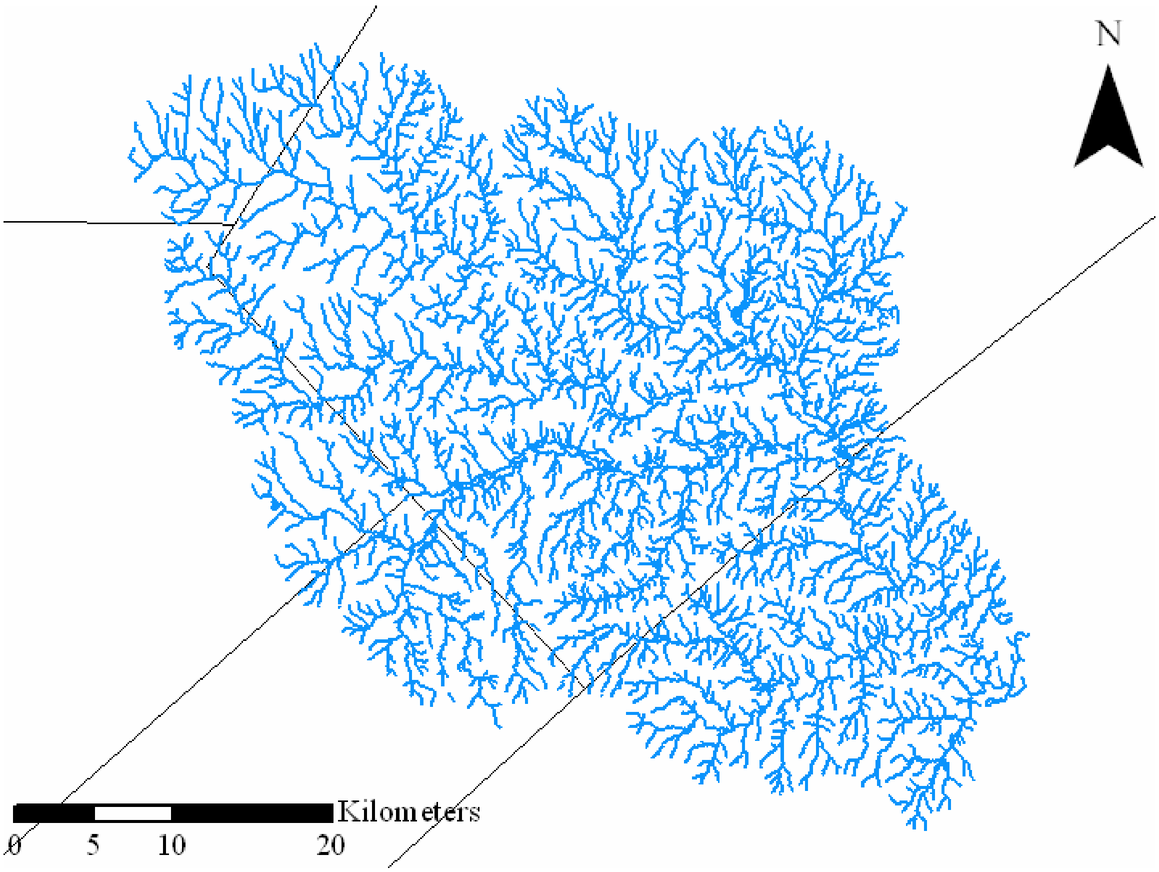

Figure 5.6: NHD High-Resolution Flowlines for the Sandies and Elm Watershed

5.2.5 Topography

Digital raster images of the 1/3 arc second topographic information were downloaded from the USGS: Seamless site as seen in Figure 5.7. (USGS: Seamless, 2005) The National Elevation Dataset (NED) 1/3 Arc Second is a raster product assembled by the USGS. NED 1/3 Arc Second is designed to provide National elevation data in a seamless form with a consistent datum, elevation unit, and projection. NED 1/3 Arc Second has a resolution of 1/3 arc-second which is approximately 10 meters. The dataset is referenced to NAD83 as horizontal datum, and all the data are recast in a geographic projection. (USGS: Seamless, 2006b)

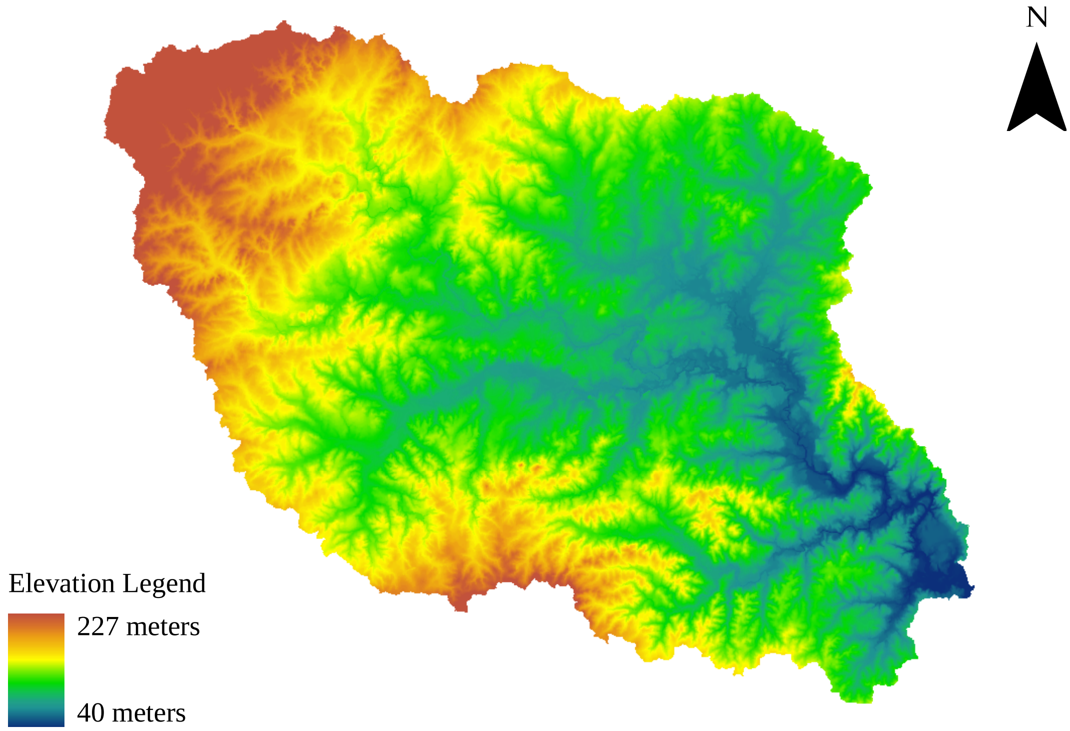

Figure 5.7: 1/3 Arc Second National Elevation Data (USGS: Seamless, 2005)

5.2.6 Geology and Soils

Detailed soil infiltration information is helpful for hydrologic modeling on large scales. For the United States two databases are available from the United States Department of Agriculture, Natural Resource Conservation Service: the Soil Survey Geographic (SSURGO) database and the State Soil Geographic (STATSGO) database. The STATSGO database was developed from 1:250,000 scale soil maps and the SSURGO information was developed from 1:24,000 scale soil maps. Figure 5.8 shows the STATSGO coverage for the Hydrologic Soil Groups (A, B, C, and D). Descriptions of hydrologic soil groups are summarized in Table 5.2.

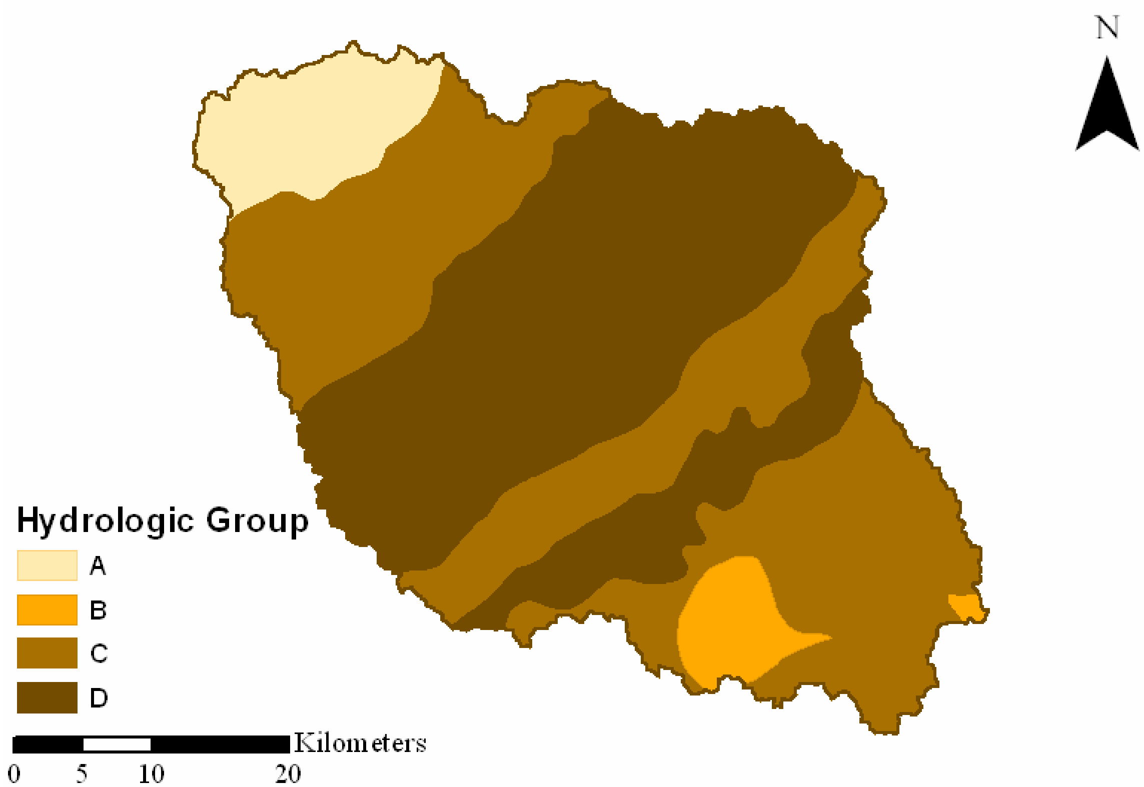

Figure 5.8: STATSGO Hydrologic Soil Groups

Table 5.2: Hydrologic Soil Groups

Hydrologic Group	**Description**
A	High infiltration rates. Soils are deep, well drained to excessively drained sands and gravels
B	Moderate infiltration rates. Deep and moderately deep, moderately well and well-drained soils with moderately course textures.
C	Slow infiltration rates. Soils with layers impeding downward movement of water, or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have a high water table.

5.2.7 Stream Flow

Daily stream flow data from the USGS gage 08175000 on Sandies Creek at Westhoff, Texas in DeWitt County was used to calibrate the hydrologic portion of the HSPF model. The gage is located at 29º12'54" North and 97º26'57" West (NAD 27) and is 178.27 feet (54.34 meters) above sea level (NGVD29). The gage has a contributing area of 549 square miles.

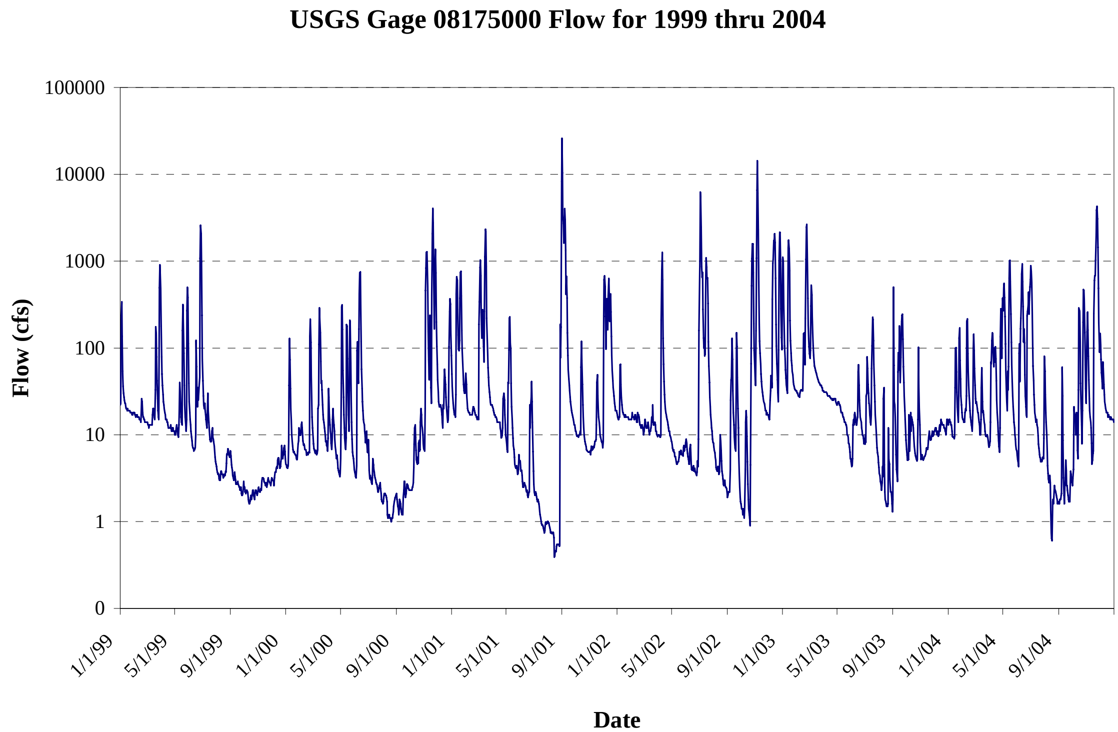

Figure 5.9: Sandies Creek USGS Gage Flow 1999 thru 2004

5.3 MODEL CONSTRUCTION

HSPF models simulate a watershed through a sequence of HSPF processes which each simulate a finite portion of the watershed. HSPF has two types of operations that simulate the land surface, Pervious Land Segments (PERLND) and Impervious Land Segments (IMPLND). These two land segment processes are frequently linked to Reach

Segment Operations (RCHRES), which simulate the flow of water in rivers. Water flowing across the land to rivers is intrinsic to the movement of water in the environment and is the driving force in non-point source pollution. It is, therefore, an understandable choice for the elemental structure of an HSPF model.

Many decisions beyond this basic structure are made by the modeler. These decisions eventually influence how the overall character of the watershed is displayed. These choices include many items, but the degree to which the model is lumped or distributed is of paramount importance. The terms “Lumped” and “Distributed” have explicit connotations when describing mathematical models, see Chapter Two. The designation of a model with one of these two categories involves both the spatial scale and techniques used for the solution. HSPF and the processes within the model are “Lumped.” HSPF does not consider the partial derivatives of processes with respect to space in simulations. (Singh and Woolhiser, 2002)

Despite these explicit definitions, when describing HSPF model configurations, the terms “Lumped” and “Distributed” are often used to describe the degree to which the land surface and river systems have been segmented. “Lumped” often means that large areas of land which may or may not have similar spatially variable properties are simulated as a single Land Segment. “Distributed” often means that an attempt was made to segment the model so that spatially variable parameters and data are relatively uniform over an individual Land Segment.

One of the motivating factors in configuring an HSPF model is the desire to capture the spatial variability of processes occurring on or over the land surface. As explained in Chapter Three, there is significant spatial variability in precipitation over the Sandies and Elm watershed that is not described through the available hourly or daily NCDC stations. Therefore, NEXRAD precipitation data was used for this model. This choice of precipitation data type is an important factor in the configuration of the HSPF model. The structure of HSPF processes for land segments requires that forcing data such as rainfall be applied uniformly over the land segment. HSPF processes are often broken down to represent an area with homogeneous land use and soil characteristics, but because of the structure of the HSPF model, the entire area represented by an HSPF Operation must also receive uniform forcing data, in this case, precipitation. Therefore, even if two areas of land have identical land use, topographic, and soil characteristics, if they do not receive the same amount of precipitation, they must be modeled with two separate HSPF Operations.

A second motivating factor in the model creation process is the overall objective behind the model. The purpose of this water quality model requires that results be produced at specific locations along the river network for calibration of the model to monitored bacteria levels. This objective requires that river segments be divided at locations where monitoring station exist so that model results can be directly compared with observed data.

5.3.1 Watershed Delineation

Keeping in mind both of the motivating factors in the structure of the watershed model, the Sandies and Elm watershed was delineated. The subbasins were delineated on a small enough scale in order to capture the spatial variability of precipitation across the basin and with breaks at the bacteria and flow monitoring stations.

5.3.2 River Reaches

The underlying structure of the watershed delineation was in the physical locations of the stream segments as defined by the high-resolution NHD. There were a total of over 2000 reach segments in the high-resolution dataset. This number was excessive and was, therefore, reduced to 107 by eliminating the un-named streams from the total. The rationale for this is that, without any actual field data available, the named streams were the more important in the basin and more often contained flowing water. Figure 5.10 shows the high-resolution NHD streams that were used in modeling the Sandies and Elm watershed.

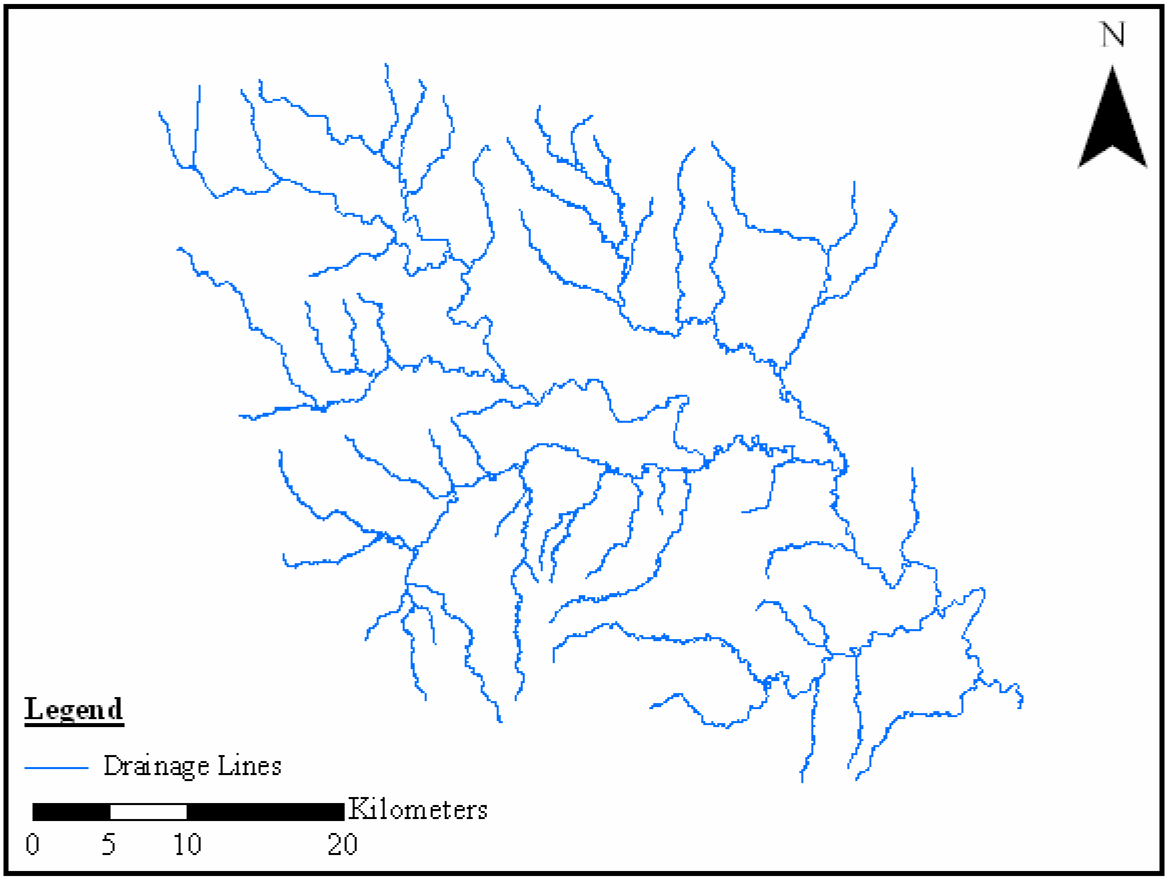

Figure 5.10: Sandies and Elm Drainage Lines

WRAP Hydro was then used to find the subbasin areas for each of the named streams in the NHD stream network within the Sandies and Elm watershed.

5.3.3 Subbasins

Figure 5.11 shows the subbasin delineation for the Sandies and Elm watershed. Once the subbasins were delineated it was noted that the watershed would need to be broken up into two models, an upper and a lower section, to allow for an adequate number of land uses to be applied within each subbasin. The reason for this is explained in Section 5.3.4.

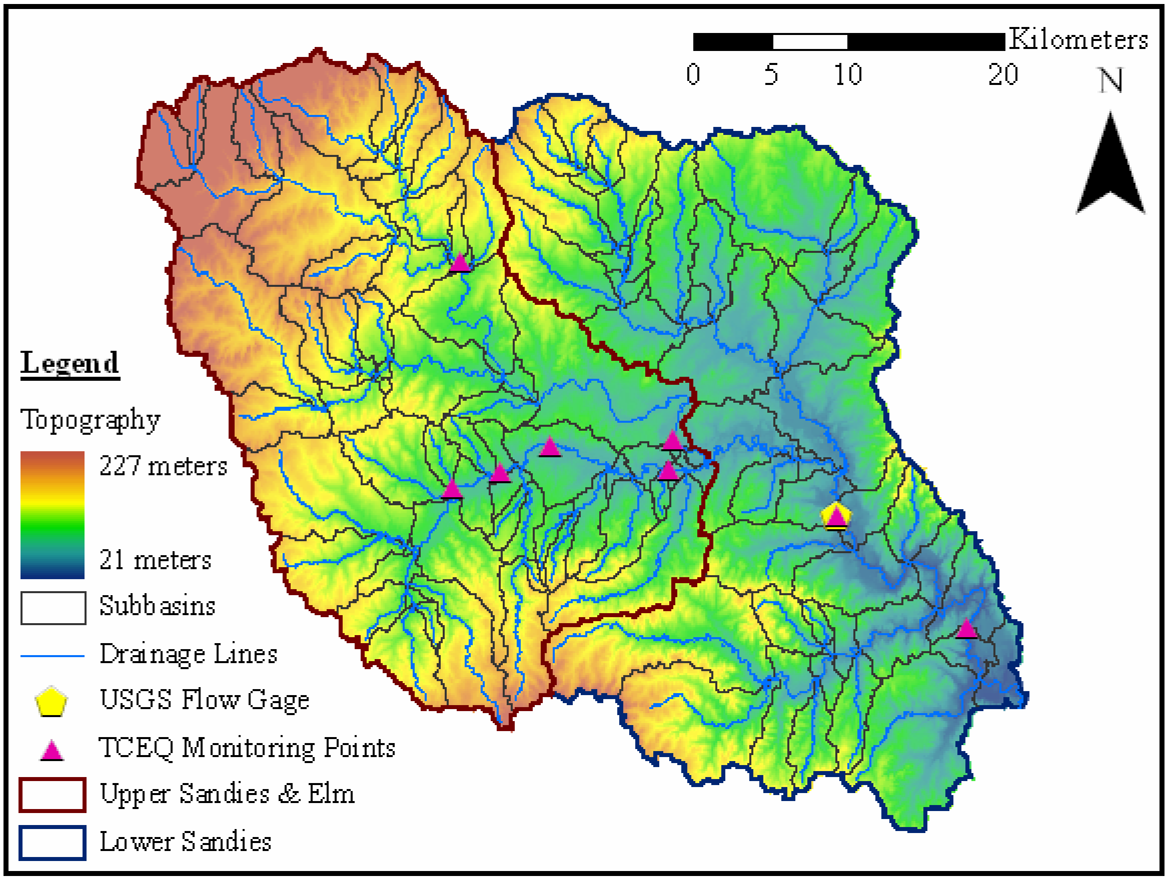

Figure 5.11: Sandies and Elm Watershed Delineation

The subbasins range in size from 0.4 square kilometers to 67.0 square kilometers with a mean of 15.3 square kilometers in the Upper Sandies and Elm and from 0.6 square kilometers to 70.4 square kilometers with a mean of 19.9 square kilometers in the Lower Sandies. There are 107 subbasins in the Sandies and Elm watershed that are, on average, 18 square kilometers in size, which is comparable to the approximately 124 NEXRAD cells across the watershed that are 16 square kilometers in size. Therefore, the subbasin delineation should adequately represent the spatial variability of the precipitation over the watershed.

5.3.4 Land Use / Land Cover

As described in Chapter Two, HSPF applies an Operation to a land segment, or land use type, even if that land segment is not spatially contiguous within the zone of the Operation. The basis for this choice of the characterization of spatially discontinuous areas of land with a single Land Segment is associated with the process used to model water movement over the land surface. HSPF processes calculate a vertical water balance, and if a type of land segment within a subbasin has similar land surface characteristics, there is no reason to consider that a water balance over an area will be different even if they are not connected.

GIS data commonly contains 21 or more categories of land use / land cover, but HSPF models typically simulate fewer than 10 types of land use. Reduction of total land use types into a coherent group is defined by both the watershed and the model focus.

The Sandies and Elm basin is agricultural in nature and the focus of the TMDL study is non-point source pollution associated with the agricultural practices in the watershed. The USGS Seamless raster information for land use / land cover is shown in Figure 5.5. The Sandies and Elm basin includes 17 of the 21 possible land use / land cover types. The total number of land use types was reduced for the HSPF model to the land use categories listed in Table 5.3.

The HSPF categories were chosen by defining the major uses in the watershed and combining the minor uses with similar traits. For instance, the Bare Rock and Quarries land use was added into the Developed land use because of the impervious nature of all land types included in the category. In addition the very small percentage of the total watershed area represented by these land uses implies that the differences between the grouped types are inconsequential. The areas were further reduced to keep the number of categories at or below six. HSPF has a limit to the number of operation sequences that can be performed from an input file, 500. This limit, along with the number of delineated subbasins, restricted the number of land uses that could be applied to six. An illustration of the above reclassification is shown in Figure 5.12.

Table 5.3: Land Use Breakdown

<table>
<tr><th colspan="2">Seamless Land Use / Land Cover</th><th colspan="3">HSPF Land Use / Land Cover</th></tr>
<tr><th>Categories</th><th>Percentage</th><th>Percentage</th><th>Pervious Categories</th><th>Impervious Categories</th></tr>
<tr><td>Light Residential</td><td>0.08%</td><td rowspan="6">0.63%</td><td rowspan="6">Developed</td><td rowspan="6">Developed</td></tr>
<tr><td>Heavy Residential</td><td>0.03%</td></tr>
<tr><td>Commercial/Indust</td><td>0.27%</td></tr>
<tr><td>BareRock/Sand/Clay</td><td>0.13%</td></tr>
<tr><td>Quarries/StripMines</td><td>0.08%</td></tr>
<tr><td>Rec. Grasses</td><td>0.03%</td></tr>
<tr><td>Deciduous Forest</td><td>19.62%</td><td rowspan="3">25.00%</td><td rowspan="3">Forest</td><td rowspan="11"></td></tr>
<tr><td>Evergreen Forest</td><td>5.36%</td></tr>
<tr><td>Mixed Forest</td><td>0.02%</td></tr>
<tr><td>Shrubland</td><td>21.04%</td><td>21.04%</td><td>Shrubland</td></tr>
<tr><td>Grassland</td><td>24.27%</td><td>24.27%</td><td>Grassland</td></tr>
<tr><td>Pasture</td><td>24.79%</td><td rowspan="3">28.54%</td><td rowspan="3">Planted</td></tr>
<tr><td>Row Crops</td><td>3.46%</td></tr>
<tr><td>Small Grains</td><td>0.30%</td></tr>
<tr><td>Woody Wetlands</td><td>0.09%</td><td rowspan="3">0.52%</td><td rowspan="3">Wetlands</td></tr>
<tr><td>Herbaceous Wetlands</td><td>0.12%</td></tr>
<tr><td>Open Water</td><td>0.31%</td></tr>
</table>

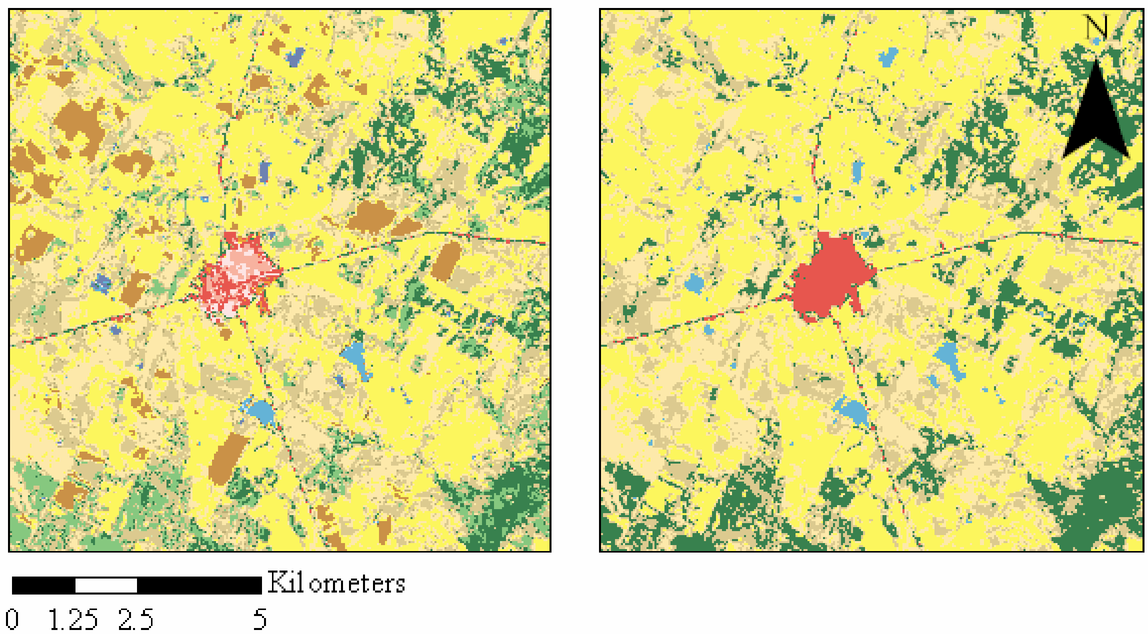

Figure 5.12: Reclassification of Land Uses for HSPF Model

ArcGIS tools were used to translate USGS land use categories into HSPF land use categories. Figure 5.13 illustrates the process of calculating the amount of each land use type that contributes to each river segment. Subbasin areas overlay the condensed land use polygons to identify the land use allocation in each.

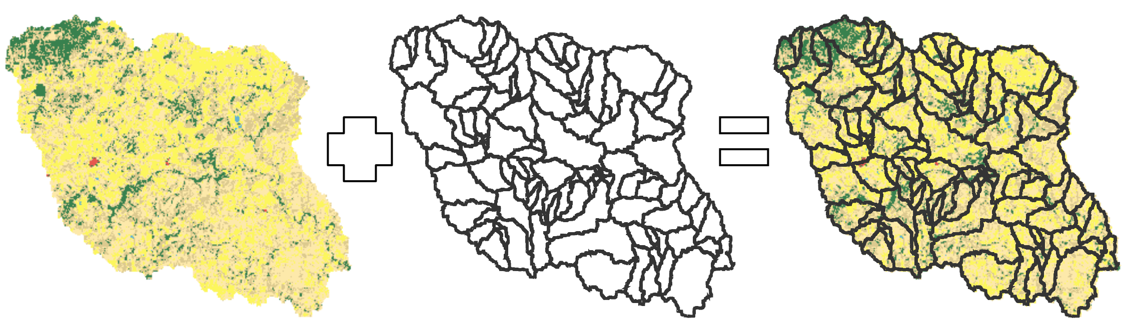

Figure 5.13: Land Use / Subbasin Intersection Illustration

The result of the application illustrated in Figure 5.13 is a polygon feature class in which each feature represents the area of a single land use type that contributes to a single river segment. (Figure 5.14) (Johnson, 2005)

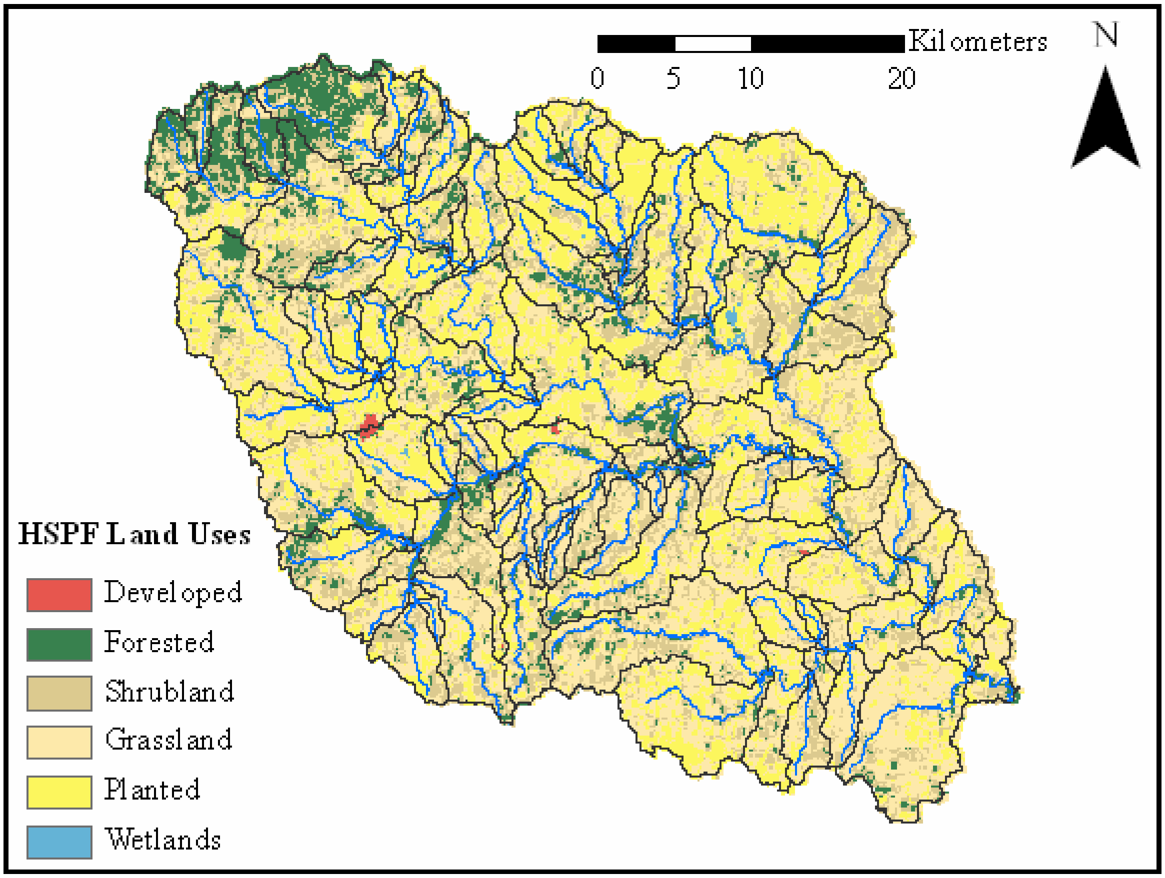

Figure 5.14: HSPF Land Uses and Subbasins

5.3.5 Cross-Section and Outflow

In HSPF, the outflow of water from the River Segments is modeled using a simple volume or stage vs. discharge relationship. A lumped flow routing scheme is applied using an invariable, single valued storage function relating discharge from the segment to storage in the segment. (Bicknell *et al.*, 2001)

The USGS historical stage-discharge information for USGS gauging station 08175000 was downloaded from the National Water Information System (NWIS) website. (USGS: NWIS, 2005) The USGS gauging station for the Sandies and Elm Watershed is located near Westhoff, Texas and drains 549 square miles at that point, which is 79.75% of the total watershed. The historical information was evaluated for Width vs. Flow and Width vs. Low Flow as shown in Figure 5.15 and Figure 5.16.

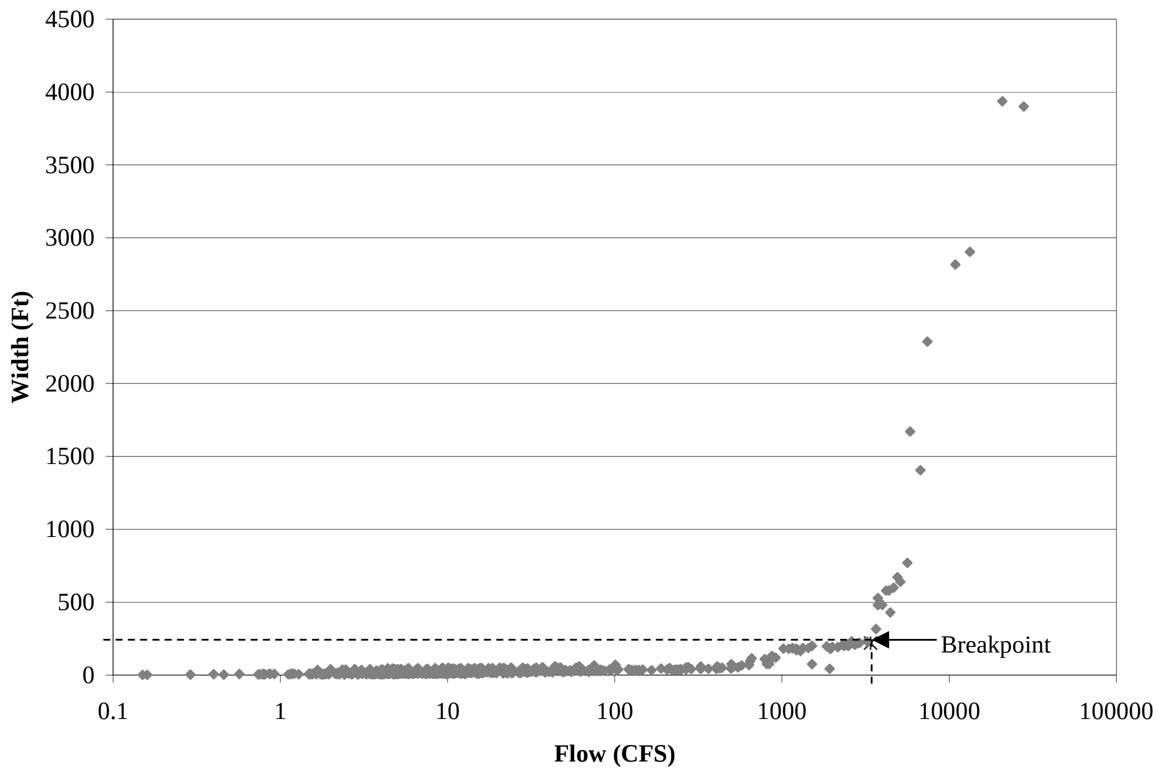

Figure 5.15: USGS Gaging Station 08175000 Historical Width versus Flow

Distinct changes in the relationship between width and flowrate are evident in these figures. A change in the slope for the USGS Gaging Station 08175000 occurs at a high flowrate of 3390 CFS and 219-ft width. A low flow change in slope or break occurs at about 438 CFS and 50-ft width. These flows are associated with 8.65 ft and 20 ft in depth respectively. (Figure 5.17)

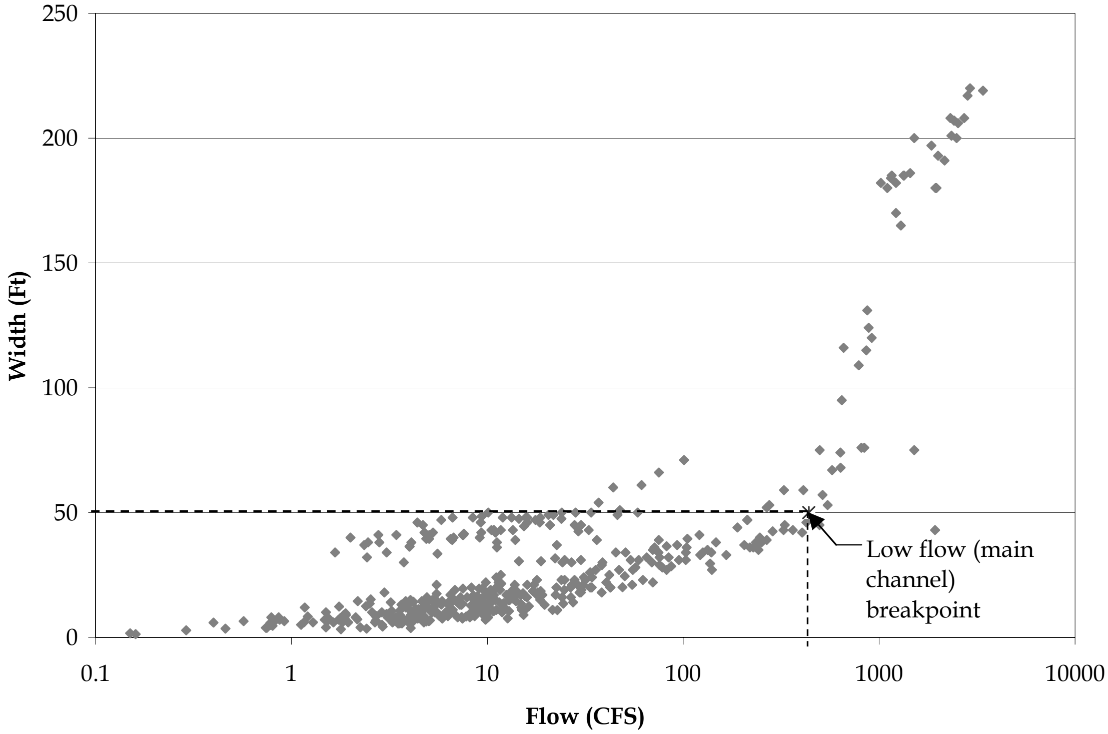

Figure 5.16: USGS Gaging Station 08175000 Historical Width versus Low Flow

The minimum width of the cross-section fluctuates around the 5 to 7 foot mark. A side-slope of 2.5:1 was estimated, which with a 50-ft width and 8.65-ft depth allowed a bottom width of 6.75 feet, which falls within the USGS data range. Analysis of the historical data, in the above fashion, produces a cross-section at the gauging station with distinct breaks at certain widths and depths as depicted in Figure 5.18.

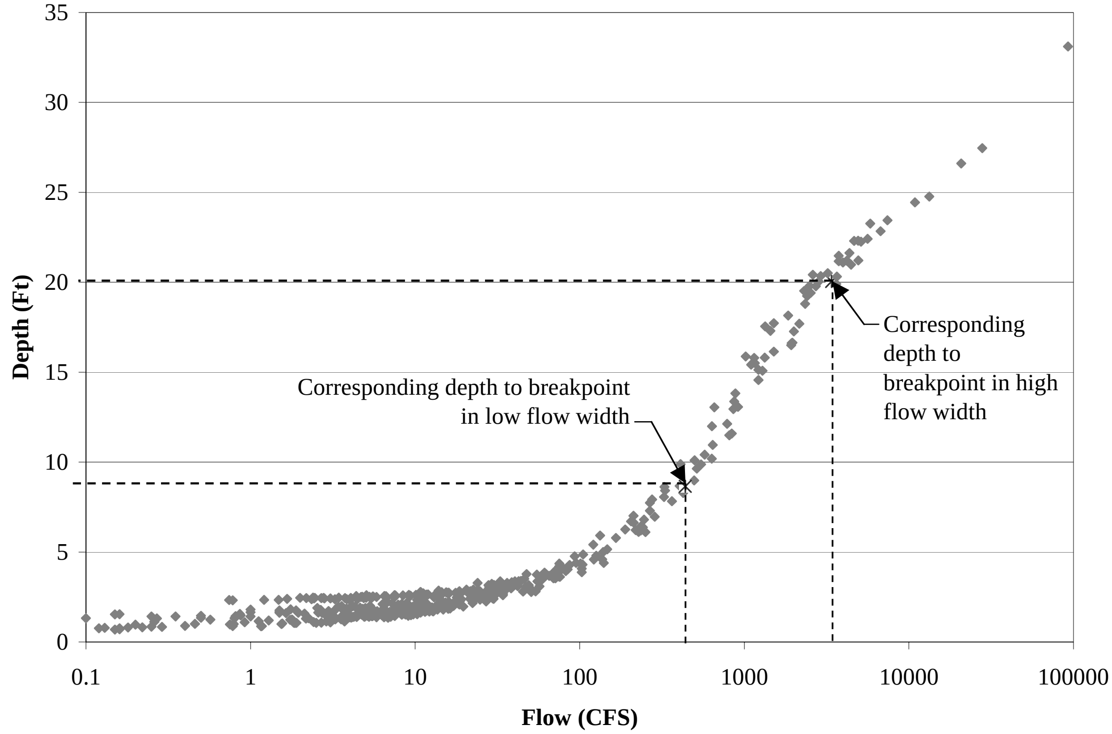

Figure 5.17: USGS Gaging Station 08175000 Historical Depth versus Flow

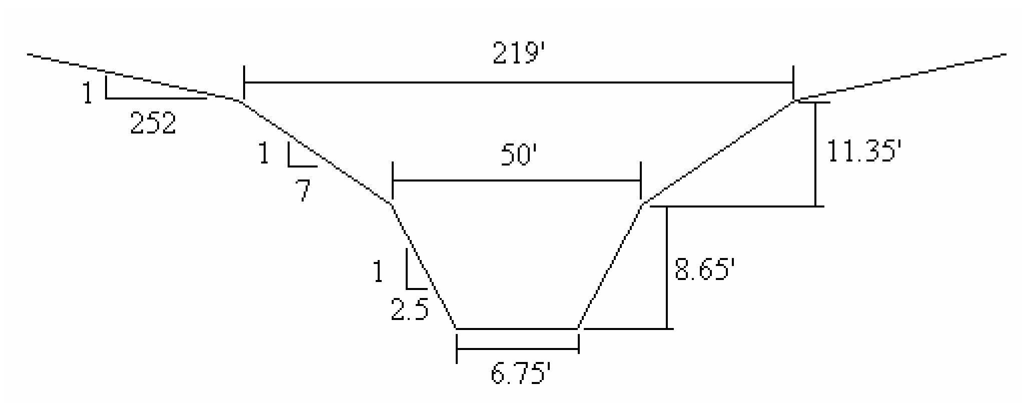

Figure 5.18: Historical Cross-Section at USGS Gauge 08175000

A stage-discharge relationship needed to be defined for each reach in the entire river network of the Sandies and Elm watershed. Field flow rates and survey data were unavailable; therefore the stage discharge relationship was derived for the whole watershed from the data available from the USGS gauging station. From the historical cross-section and flow data the reach cross-sections were estimated in the following way.

First a watershed drainage area to main channel flow relationship was defined. According to the historical data, the main channel allows 438 CFS of water flow for 549 square miles of drainage area. Therefore, main channel relationship is:

Equation 5.1: Main Channel Flow

Main Channel Flow = 0.798 CFS/square mile

Similarly the Lower and Upper Floodplain Flows were defined.

Equation 5.2: Lower Floodplain Flow

Lower Floodplain Flow = 6.175 CFS/square mile

Equation 5.3: Upper Floodplain Flow

Upper Floodplain Flow = 38.616 CFS/square mile

These relationships were used to define the flows for each reach in the HSPF model stream network.

The bottom width of the channel was defined by dividing the 6.75 ft. bottom width, from the historical data, by 549 square miles. This number was then rounded to the nearest 0.05 feet.

Equation 5.4: Bottom Width

Bottom Width = 0.0123 feet/square mile

From here the rest of the cross-section was defined by geometry and Manning's equation.

Equation 5.5: Manning's Equation

$$Q = \left[\frac{1.49}{n} \left(\frac{A}{P} \right)^{2/3} S^{1/2} \right] A$$

n: Manning's Coefficient
A: Cross-Sectional Area
P: Wetted Perimeter
S: Longitudinal Slope

Manning's coefficient was set to values of 0.05 for the Main Channel and 0.07 for both the Upper and Lower Floodplains.

Equation 5.6: Top Width

Top Width = Bottom Width + (2 * Side Slope * Depth)

The side slopes were defined by the gauge historical data cross-section using the values in Table 5.4 for side slopes.

Table 5.4: Section Side Slope

Section	**Side Slope**
Main Channel	2.5:1
Lower Floodplain	7:1
Upper Floodplain	252:1

From these equations, an Excel spreadsheet was set up to optimize the depth using Manning's equation to match the required flow and the geometric relationships defined above. See tables in Appendix C for all channel cross-sections defined this way.

5.3.6 Physical Parameter Definition

There are a few parameters in an HSPF model that can either be defined or initially estimated from readily available information on the physical watershed. The parameters listed in Table 5.5 were calculated using know physical parameters.

Table 5.5: HSPF Physical Parameters

Name	Units	Range of Values				Function of
		Typical		Possible		
		Min	Max	Min	Max	
PWATER – PARAMETER SET 2						
LZSN	Inches	3.0	8.0	2.0	15.0	Soils, Climate
INFILT	In/hr	0.01	0.25	0.001	0.50	Soils, Land Use
LSUR	Feet	200	500	100	700	Topography
SLSUR	Ft/ft	0.01	0.15	0.001	0.30	Topography
PWATER – PARAMETER SET 4						
CEPSC	Inches	0.03	0.20	0.01	0.40	Vegetation Type/Density
UZSN	Inches	0.10	1.0	0.05	2.0	Surface Soil Conditions
NSUR	None	0.15	0.35	0.05	0.50	Surface Conditions
LZETP	None	0.2	0.7	0.1	0.9	Vegetation Type/Density

The parameters highlighted in yellow were calculated. The parameters highlighted in blue were estimated and then calibrated.

5.3.7 Length of Overland Flow Plane (LSUR)

Length of overland flow plane (LSUR) approximates the average length of travel for water to reach a stream reach or any drainage path within the subbasin. The length of overland flow can be estimated from the drainage density of the subbasins. The drainage density is defined as the sum of all drainage path lengths divided by the area. To find the drainage density ArcGIS was utilized. All of the drainage lines in the high-resolution National Hydrography Dataset were used to calculate the total drainage path length, and that length was divided by the subbasin area to find the drainage density.

Equation 5.7: Overland Flow (LSUR)

$$\text{Overland Flow (LSUR)} = (2 * \text{Drainage Density})^{-1}$$

The statistics of the drainage densities calculated for the subbasins in the Upper Sandies and Elm and Lower Sandies are listed in Table 5.6. Appendix E lists all of the LSUR values for each of the subbasins.

Table 5.6: Drainage Density Statistics (kilometer/square kilometer)

	Upper Sandies & Elm	**Lower Sandies**
Minimum	0.96	1.43
Maximum	5.95	5.63
Mean	2.00	2.00
Standard Deviation	0.88	0.66

Patton and Baker (1976) estimated the drainage density of streams in central Texas to be around 4.05 kilometer/square kilometer. The drainage densities calculated for the Sandies and Elm watershed were, for the most part, lower than this average. This could be due to the level of streams shown in the high-resolution NHD.

5.3.8 Slope of Overland Flow Path (SLSUR)

SLSUR was calculated using the ArcGIS to HSPF Preprocessing Methodology. (Johnson, 2005) Utilizing ArcGIS Zonal Statistics and the Digital Elevation Model, the maximum and minimum elevations for each subbasin are calculated. The difference in these elevations is then divided by the output of the ArcHydro tool, Longest Flow Path, for each subbasin. This calculation gives a general estimate for the slope of the terrain within each subbasin.

5.3.9 Manning's n for Overland Flow Plane (NSUR)

NSUR values were defined based on land use / land cover. An average of the values given in EPA BASINS Technical Note 6 (US EPA, 2000) for different land uses was applied to the six land uses defined for the Sandies and Elm watershed. Table 5.7

lists the NSUR parameters used for the Sandies and Elm watershed along with the associated land use description and range from Technical Note 6. (US EPA, 2000)

Table 5.7: Sandies & Elm NSUR Parameters

Land Use	Technical Note 6 Description	Tech. Note 6 Range	NSUR
Developed	Normal Roads and parking lots	0.10	0.10
Forest	Heavy turf, forest litter	0.30 – 0.45	0.35
Shrubland	Moderate turf / pasture (high)	0.20 – 0.30	0.30
Grassland	Moderate turf / pasture (low)	0.20 – 0.30	0.20
Planted	Rough fallow / cultivated	0.20 – 0.30	0.25
Wetlands	Same as river bed		0.05

5.3.10 Lower Zone Evapotranspiration (LZETP)

LZETP is an index to the lower zone evapotranspiration. It is a coefficient that defines the opportunity for evapotranspiration. The LZETP was estimated from the land use value ranges given in EPA BASINS Technical Note 6. (US EPA, 2000) Values were applied on a monthly basis with land use / land cover type. See Table 5.8 for monthly values of LZETP for each land use and month.

Table 5.8: LZETP Monthly Values per Land Use

Land Use	LZETP											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Developed	0.05	0.05	0.10	0.15	0.20	0.25	0.35	0.30	0.25	0.20	0.15	0.10
Forest	0.15	0.15	0.30	0.40	0.50	0.60	0.70	0.80	0.60	0.50	0.40	0.30
Shrubland	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.45	0.40	0.30	0.20
Grassland	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.45	0.40	0.30	0.20
Planted	0.15	0.15	0.30	0.40	0.50	0.60	0.70	0.70	0.55	0.40	0.30	0.20
Wetlands	0.20	0.20	0.40	0.50	0.60	0.70	0.80	0.90	0.80	0.70	0.50	0.30

5.3.11 Lower Zone Nominal Soil Moisture Storage (LZSN)

LZSN is related to both precipitation patterns and soil characteristics of a watershed. Technical Note 6 (US EPA, 2000) provides an initial estimate calculation method for the LZSN by Viessman, *et al*. (1989). Viessman *et al*. estimated the LZSN to be one-quarter of the mean annual rainfall plus four inches for arid to semi-arid regions, or one-eighth annual mean rainfall plus four inches for coastal, humid, or subhumid climates. But, it is noted that this formula tends to estimate values higher than what is seen in final calibrated models. A Viessman calculation estimates LZSN at 8.1 to 12.3 inches for the Sandies and Elm watershed.

5.3.12 Index to Mean Soil Infiltration Rate (INFILT)

INFILT is the mean soil infiltration rate in inches per hour. It is the parameter that effectively controls the overall division of the available moisture from precipitation (after interception – see section below) into surface and subsurface flow. Since INFILT is not a maximum rate nor an infiltration capacity term, its values are normally much less than published infiltration rates found in literature. (US EPA, 2000) INFILT is primarily based on soil characteristics and ranges of values have been related to the SCS hydrologic soil groups. See Table 5.9.

Table 5.9: SCS Hydrologic Soil Group Characteristics

Hydrologic Group	Description
A	High infiltration rates. Soils are deep, well drained to excessively drained sands and gravels
B	Moderate infiltration rates. Deep and moderately deep, moderately well and well-drained soils with moderately course textures.
C	Slow infiltration rates. Soils with layers impeding downward movement of water, or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have a high water table.

5.3.13 Rainfall Vegetation Interception (CEPSC)

CEPSC is the amount of precipitation that is captured by vegetative cover and never reaches the land surface, in inches. Values for maximum interception range from 0.10 to 0.25. Monthly values are normally used for interception rates in largely agricultural areas. (US EPA, 2000) Table 5.10 presents monthly interception rates used for the Sandies and Elm watershed model.

Table 5.10: Monthly Interception Rates (Inches)

Land Use	CEPSC											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
All	0.00	0.00	0.02	0.04	0.08	0.10	0.10	0.10	0.10	0.05	0.03	0.01

5.3.14 Nominal Upper Zone Soil Moisture Storage (UZSN)

UZSN is the nominal upper zone soil moisture storage, in inches. US EPA Technical Note 6 provides an estimate method by Donigian and Davis (1978) for an initial UZSN estimate. Donigian and Davis calculate UZSN to be 0.06 of LZSN for steeply sloping terrain or light vegetative cover; 0.08 of LZSN for moderately sloping terrain or moderate vegetative cover; and 0.14 of LZSN for heavy vegetative cover. The initial estimate of UZSN, by this definition, would be from 0.50 to 1.72, given the above LZSN range of 8.1 to 12.3.

This chapter has explained the development of the model from the known physical aspects. The HSPF model of the Sandies and Elm watershed requires this information for model calibration. The next chapter explains the process and results of the calibration of those parameters which can not be determined based on available data or known physical processes.

Chapter 6 Model Calibration

The calibration of the Sandies and Elm HSPF model followed the standard model calibration procedures described in the HSPF Application Guide (Donigian *et al*., 1984). The following model calibration explanation focuses exclusively on the HSPF hydrologic parameters; water quality parameters are not discussed.

6.1 PARAMETER ESTIMATION

Calibration of an HSPF model is an iterative process of parameter estimation comparison and refinement. This approach is required for parameters that cannot be uniquely determined from known physical characteristics of the watershed. Simulated model flow and observed flow data are compared so that the undetermined parameters can be calibrated to the observed hydrologic data. Fortunately, a minority of HSPF parameters fall into this category. Table 6.1 below lists the PWATER parameters that can be varied during model calibration, normal ranges of these parameters, and possible sources for initial parameterization. A number of these parameters initial estimates were discussed in the previous chapter.

The result of a model calibration is a set of parameters that produce the best overall agreement between simulated and observed values during the calibration period based on standard statistical measures.

Table 6.1: HSPF PWATER Parameters (US EPA, 2000)

Name	Units	Range of Values				Function of	Comment
		Typical		Possible			
		Min	Max	Min	Max		
PWATER – PARAMETER SET 2							
FOREST	None	0.0	0.50	0.0	0.95	Forest Cover	Only when SNOW is active
LZSN	Inches	3.0	8.0	2.0	15.0	Soils, Climate	Calibration
INFILT	In/hr	0.01	0.25	0.001	0.50	Soils, Land Use	Calibration
LSUR	Feet	200	500	100	700	Topography	Estimate from topography, GIS
SLSUR	Ft/ft	0.01	0.15	0.001	0.30	Topography	Estimate from topography, GIS
KVARY	1/inches	0.0	3.0	0.0	5.0	Baseflow Recession Variation	Used when recession rate varies with groundwater
AGWRC	None	0.92	0.99	0.85	0.999	Baseflow Recession	Calibration
PWATER – PARAMETER SET 3							
PETMAX	Deg. F	35.0	45.0	32.0	48.0	Climate, Vegetation	Only when SNOW is active
PETMIN	Deg. F	30.0	35.0	30.0	40.0	Climate, Vegetation	Only when SNOW is active
INFEXP	None	2.0	2.0	1.0	3.0	Soils Variability	Default to 2.0
INFILD	None	2.0	2.0	1.0	3.0	Soils Variability	Default to 2.0
DEEPFR	None	0.0	0.20	0.0	0.50	Geology, GW Recharge	Accounts for subsurface losses
BASETP	None	0.0	0.05	0.0	0.20	Riparian Vegetation	Direct ET from riparian vege.
AGWETP	None	0.0	0.05	0.0	0.20	Marsh Wetland Extent	Direct ET from shallow GW
PWATER – PARAMETER SET 4							
CEPSC	Inches	0.03	0.20	0.01	0.40	Vegetation Type/Density	Monthly values usually used
UZSN	Inches	0.10	1.0	0.05	2.0	Surface Soil Conditions	Near surface retention
NSUR	None	0.15	0.35	0.05	0.50	Surface Conditions	Monthly values used for Ag.
INTFW	None	1.0	3.0	1.0	10.0	Soils, Topography	Calibration
IRC	None	0.5	0.7	0.3	0.85	Soils, Topography	Start with 0.7 then adjust
LZETP	None	0.2	0.7	0.1	0.9	Vegetation Type/Density	Calibration

6.2 HSPF STANDARD CALIBRATION

A classic HSPF calibration includes a comparison of flow for annual, seasonal, and monthly time intervals, individual storm events, and flow duration curves. These different intervals are all considered in order to ensure proper calibration of the hydrological parameters of the model. This weight of evidence approach is taken because no single method has been widely accepted as being capable of creating an acceptable model. A traditional hydrologic calibration involves the successive examination of the following four components of the watershed hydrology in the subsequent order.

1) Annual water balance
2) Seasonal and monthly flow volumes
3) Baseflow
4) Storm events

Simulated and observed values for reach characteristics are examined and critical parameters are adjusted to attain acceptable levels of agreement.

6.2.1 Annual Water Balance

The annual water balance is:

Equation 6.1: Annual Water Balance

$$\text{Runoff} = \text{Precipitation} - \text{Evapotranspiration} - \text{Deep Infiltration} - \text{Change in Soil Moisture}$$

An HSPF model requires input of forcing data, in this case precipitation and evaporation, to drive the hydrology of the watershed and the model. A list, description, and range of the more important HSPF parameters for an annual water balance are shown in Table 6.2.

Table 6.2: Annual Water Balance Calibration Parameters

Parameter	Description	Range
LZSN	Lower zone soil moisture storage (inches)	3.00 – 8.00
LZETP	Vegetation evapotranspiration index (dimensionless)	0.20 – 0.70
INFILT	Infiltration index for the division of surface and subsurface flow (inches/hour)	0.01 – 0.25
UZSN	Upper zone soil moisture storage (inches)	0.10 – 1.00
DEEPFR	Fraction of groundwater inflow to deep recharge (dimensionless)	0.00 – 0.20

LZSN and LZETP affect evapotranspiration by influencing the amount of moisture available for that process. LZSN and INFILT affect the amount of precipitation that percolates. UZSN affects annual discharge volumes because of its influence on individual storm events. DEEPFR is used to represent loss from the annual water balance whenever there are losses that are measured at the flow gauge, such as recharge.

6.2.2 Seasonal and Monthly Distribution

The next step in hydrologic calibration is the seasonal or monthly distribution of runoff which is adjusted with the INFILT, AGWRC, and KVARY parameters. Seasonal distribution is accomplished by INFILT by dividing the precipitation between surface runoff, interflow, and groundwater storage. By increasing INFILT the immediate surface runoff, which includes interflow, is reduced and increases the groundwater storage. By increasing the groundwater storage this causes a delay in the time required for water to be reach the stream, which therefore moves water volume between seasons. This often means transferring the surface water from storm events to low-flow periods during the dry season. The shape of this groundwater recession, baseflow discharge, is controlled by AGWRC and KVARY. A list, description, and range of the parameters important in seasonal and monthly distribution are shown in Table 6.3.

Table 6.3: Seasonal and Monthly Distribution Parameters

Parameter	Description	Range
INFILT	Infiltration index for the division of surface and subsurface flow (inches/hour)	0.01 – 0.25
AGWRC	Groundwater recession rate (per day)	0.92 – 0.99
KVARY	Index for nonlinear groundwater recession	0.00 – 3.00

AGWRC is calculated as the rate of baseflow on one day divided by the baseflow on the previous day, therefore AGWRC is the parameter that controls the flow of water from groundwater storage into the stream. The KVARY index allows the model to have a non linear recession so that the slope of recession can be changed as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flows show a definite seasonal change in recession rate.

6.2.3 Storm Event Calibration

This is the final step in hydrologic calibration of the HSPF model after the annual water balance and seasonal and monthly distributions have been satisfied. Calibration to selected storm events was completed using the following two parameters, INTFW and IRC. A list, description, and range of the parameters important in storm calibration are shown in Table 6.4.

Table 6.4: Seasonal and Monthly Distribution Parameters

Parameter	Description	Range
INTFW	Interflow inflow parameter (dimensionless)	1.00 – 3.00
IRC	Interflow recession parameter (per day)	0.50 – 0.70

Both INTFW and IRC are used to fine-tune the shape of the hydrograph for a better fit with observed data. The parameters are first estimated from past experience and other studies in the area, and then adjusted during calibration. Adjustments to INFILT can also be made to improve simulation, but should be minor to prevent disruption in annual and monthly calibration results.

6.2.4 Specific Calibration Rules and Procedures

The previous sections described the calibration procedure in general. Below are rules that guide specific calibration procedure for parameters in the PERLND module.

1) The infiltration exponent (INFEXP) and infiltration max to mean ratio (INFILD) was set to 2.0.
2) IRC, AGWRC, and KVARY were based on calculated stream flow recessions from recorded data.
3) The length of surface runoff (LSUR), slope of surface runoff (SLSUR), and Manning's roughness for the surface runoff (NSUR) was based on the physical characteristics in the watershed.
4) Base evapotranspiration (BASETP) and active groundwater evapotranspiration (AGWETP) was initially set to zero.
5) DEEPFR was initially be set to zero, but was increased to provide a good water balance when all other parameters have been set.
6) The number one priority in this calibration process was the accurate simulation of the annual flow volumes to within a ten percent margin of observed flows.

6.2.5 Calibration Targets

The following specific comparisons of simulated versus observed flow were completed:

1. Annual Water Volume (inches)
2. Seasonal Distribution (cfs)
3. Monthly Distribution (cfs)
4. Flow Duration Curve (cfs)

The simulated and observed flows were divided into categories and then evaluated according to defined criteria so that specific flow ranges and events could be targeted. The calibration criteria are shown in Table 6.5 below. Most, but not all, of the criteria need to be met to classify the model as properly calibrated.

Table 6.5: HSPF Calibration Criteria (adapted from Donigian et al., 1984)

Calibration Target	**Simulated (-)**	**Observed (-)**	**Difference (%)**	**Criteria (%)**	**Meets Criteria***
Total (in)				10	
10% Highest (cfs)				10	
25% Highest (cfs)				15	
50% Lowest (cfs)				15	
25% Lowest (cfs)				15	
10% Lowest (cfs)				15	
Storm Volume (In)				20	
Average Storm Peak (cfs)				15	
Spring Volume (In)				15	
Summer Volume (In)				20	
Fall Volume (In)				15	
Winter Volume (In)				10	

* Excellent = more than 5% below criteria required
Good = less than Criteria required
Ok = less than 5% above criteria required
Poor = greater than 5% above criteria required

6.3 SANDIES AND ELM CALIBRATION

The model period for the Sandies and Elm watershed was six years and included years 1999 thru 2004. Model calibration resulted in parameter values that produced the best overall agreement between measured and modeled values throughout the calibration period.

The calibration process included the comparison of annual, seasonal, and monthly values as well as individual storm events. Additionally, both simulated and observed stream flow data were analyzed on a frequency basis and the resulting flow duration curves were compared to assess model conformity over the full range of storm occurrences. All of these comparisons were performed to ensure a proper calibration of hydrologic parameters.

Calibration of the Sandies and Elm watershed was atypical in the respect that the seasonal and annual water volumes were, for the most part, dependent on large storm events. The monthly flow volumes were also almost completely dependent on single storm flow values. The watershed system has so much flow variability that if the precipitation input was incorrectly estimated, even by a few percent, the flow response was incorrect and therefore the monthly, and perhaps seasonal, flow volumes were wrong.

6.3.1 Calibration Period

The full five year calibration of the model was very poor, as seen in Table 6.6. The main reason for the differences between simulated and observed data is that the flow in the Sandies and Elm watershed is defined by the large storm events and is therefore highly dependent on accurate precipitation data. The NEXRAD data, which was used for precipitation input, was missing for August 2000 to November 2000, a number of the large storm events were missed in early 2003, and storm intensity was undervalued in late 2003 through most of 2004. A data comparison of each of these missing storms can be seen in Appendix D.

As shown in Appendix D and Figure 6.1 the sequence of accurate precipitation[1] runs from January 2000 through October 2000 and April 2001 through November 2002.

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[1] A comparison of NCDC Cheapside station daily gauge precipitation against the NEXRAD precipitation in the vicinity of the gauge was completed for years 2000 through 2004. If the storm precipitation values were within 20% of each other then the storm was deemed good, else it was deemed no good. (See Appendix D for more information)

These are the sections in which the model was externally calibrated. 1999 was set aside for model internal calibration.

When only the period from April 2001 through November 2002 was evaluated the model calibration criteria was good for the annual volume and flow duration comparisons. The seasonal flow volumes were poor overall, because they depend so greatly on single storms. (See Table 6.7 and Figure 6.3 below)

Table 6.6: HSPF Calibration Criteria Results - Full Calibration Period

Calibration Target	**Simulated (-)**	**Observed (-)**	**Difference (%)**	**Criteria (%)**	**Meets Criteria**
Total (in)	10.56	15.60	32.3	10	Poor
10% Highest (cfs)	69.60	192.00	63.8	10	Poor
25% Highest (cfs)	20.00	33.00	39.4	15	Poor
50% Lowest (cfs)	12.80	14.00	8.6	15	Excellent
25% Lowest (cfs)	7.20	5.40	33.3	15	Poor
10% Lowest (cfs)	3.50	2.30	52.2	15	Poor
Storm Volume (In)	9.00	14.00	35.7	20	Poor
Average Storm Peak (cfs)	831.00	1,344.00	38.2	15	Poor
Spring Volume (In)	1.32	2.14	38.3	15	Poor
Summer Volume (In)	4.37	2.90	50.6	20	Poor
Fall Volume (In)	3.33	7.44	55.2	15	Poor
Winter Volume (In)	1.54	3.11	50.6	10	Poor

Table 6.7: HSPF Calibration Criteria Results – Shortened Calibration Period

Calibration Target	Simulated (-)	Observed (-)	Difference (%)	Criteria (%)	Meets Criteria
Total (in)	6.85	7.37	7.1	10	Good
10% Highest (cfs)	197.00	189.00	4.2	10	Excellent
25% Highest (cfs)	23.40	22.00	6.4	15	Excellent
50% Lowest (cfs)	11.10	11.00	0.9	15	Excellent
25% Lowest (cfs)	5.50	4.60	19.6	15	OK
10% Lowest (cfs)	1.40	1.70	17.6	15	OK
Storm Volume (In)	6.75	7.26	7.1	20	Excellent
Average Storm Peak (cfs)	2,569.00	3,228.00	20.4	15	Poor
Spring Volume (In)	0.44	0.29	52.2	15	Poor
Summer Volume (In)	3.44	1.67	106.1	20	Poor
Fall Volume (In)	2.60	5.01	48.1	15	Poor
Winter Volume (In)	0.37	0.39	7.4	10	Good

Because the fluctuation in flow at the gauge can change by three orders of magnitude during one storm event, it is difficult to obtain a perfect fit for each storm event in the simulation. This difference becomes very apparent in the monthly/seasonal flow data, where a slight visual difference in the daily flow on the logarithmic scale translates into significant error in the monthly cumulative analysis. See Figure 6.3.

This translates into a flow at or below 1.7 cfs. This was considered acceptable given first that the watershed has extreme flow variability and second that the calculated 7Q2, at which all water quality regulations cease to be applied, is 1.1 cfs. See Figure 6.4.

A complete listing of calibrated parameters for each subbasin is listed in Appendix E.

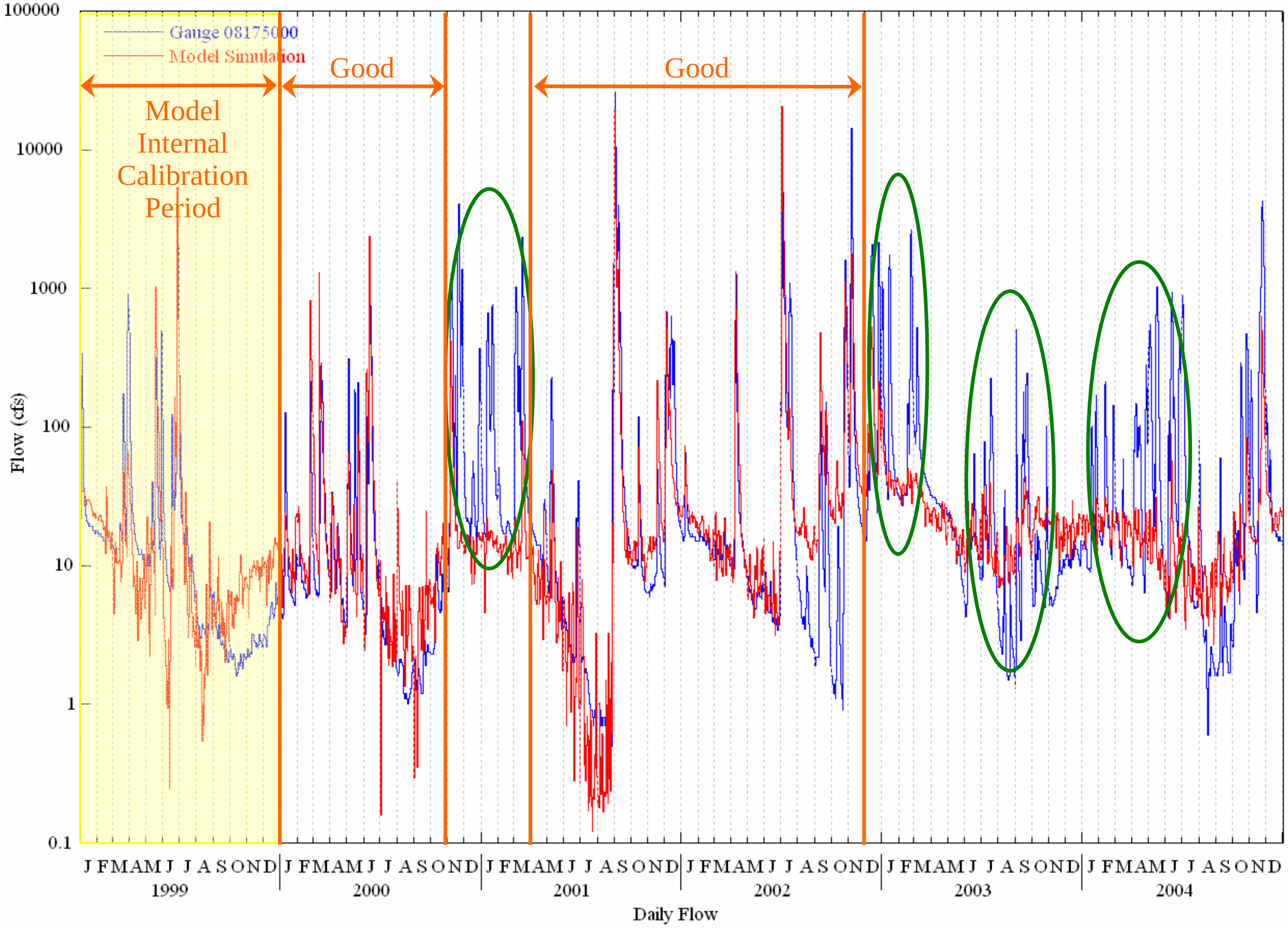


Figure 6.1: Daily Flow

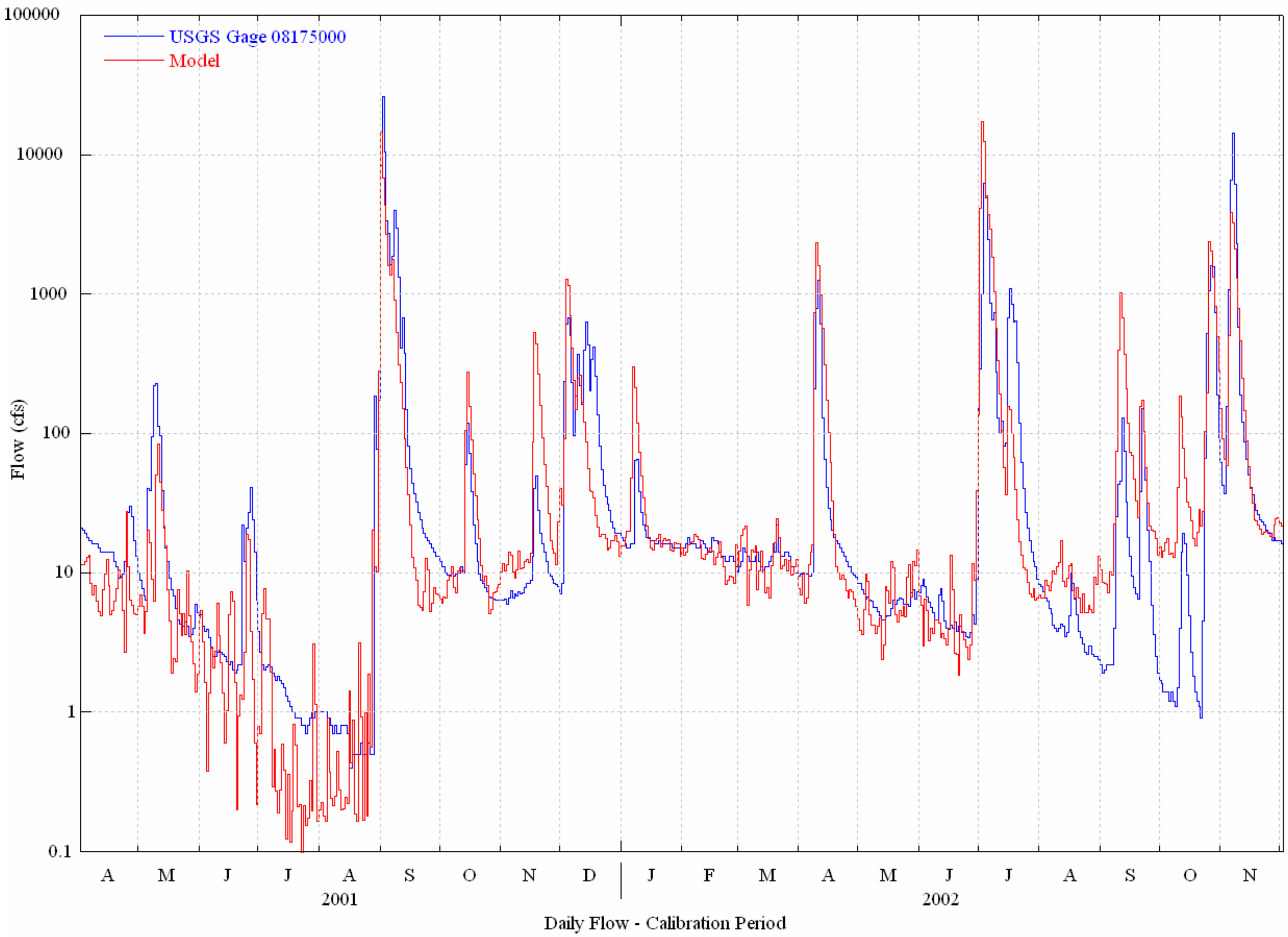


Figure 6.2: Daily Flow Calibration Period

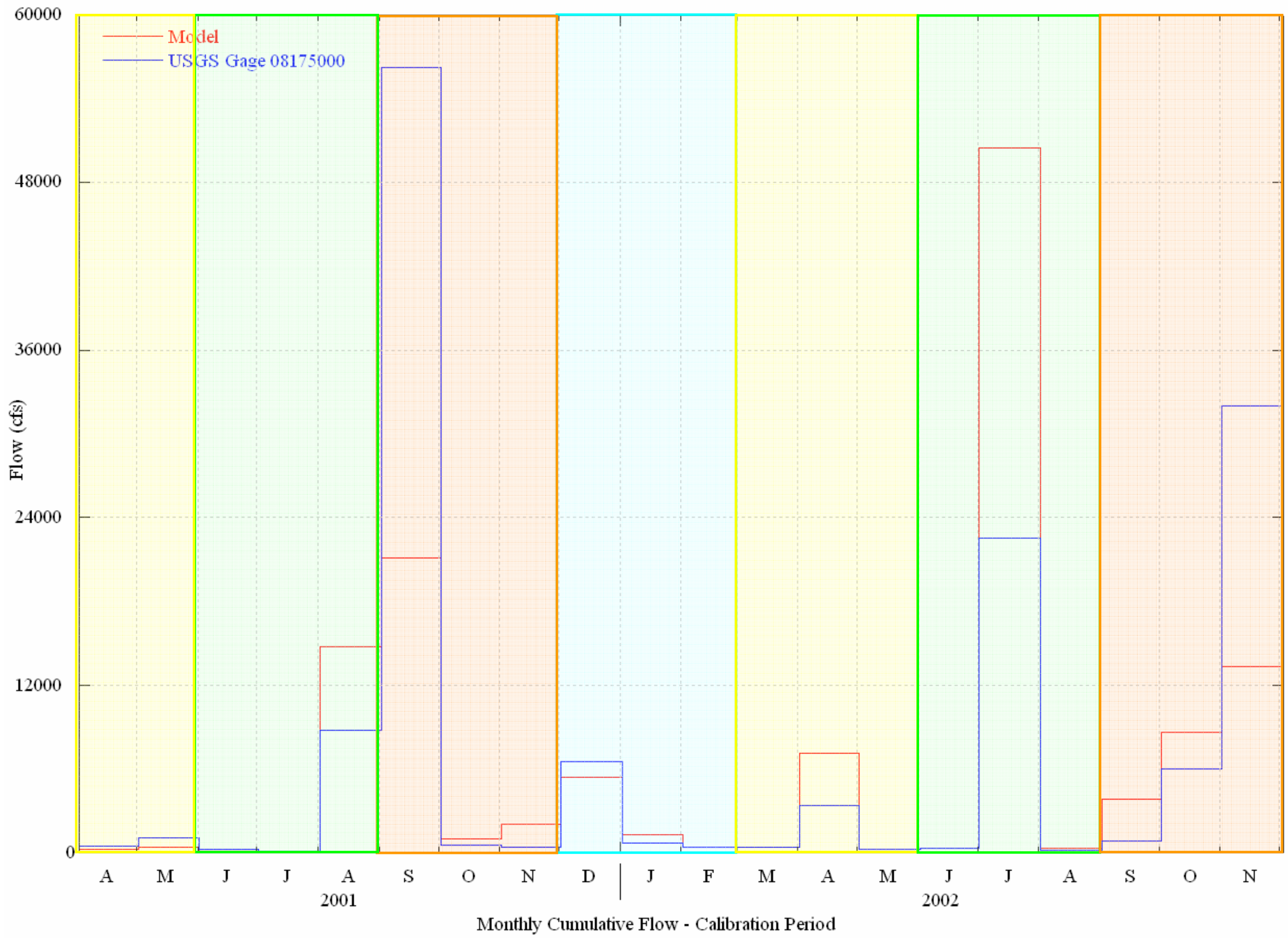


Figure 6.3: Monthly Cumulative Flow - Calibration Period

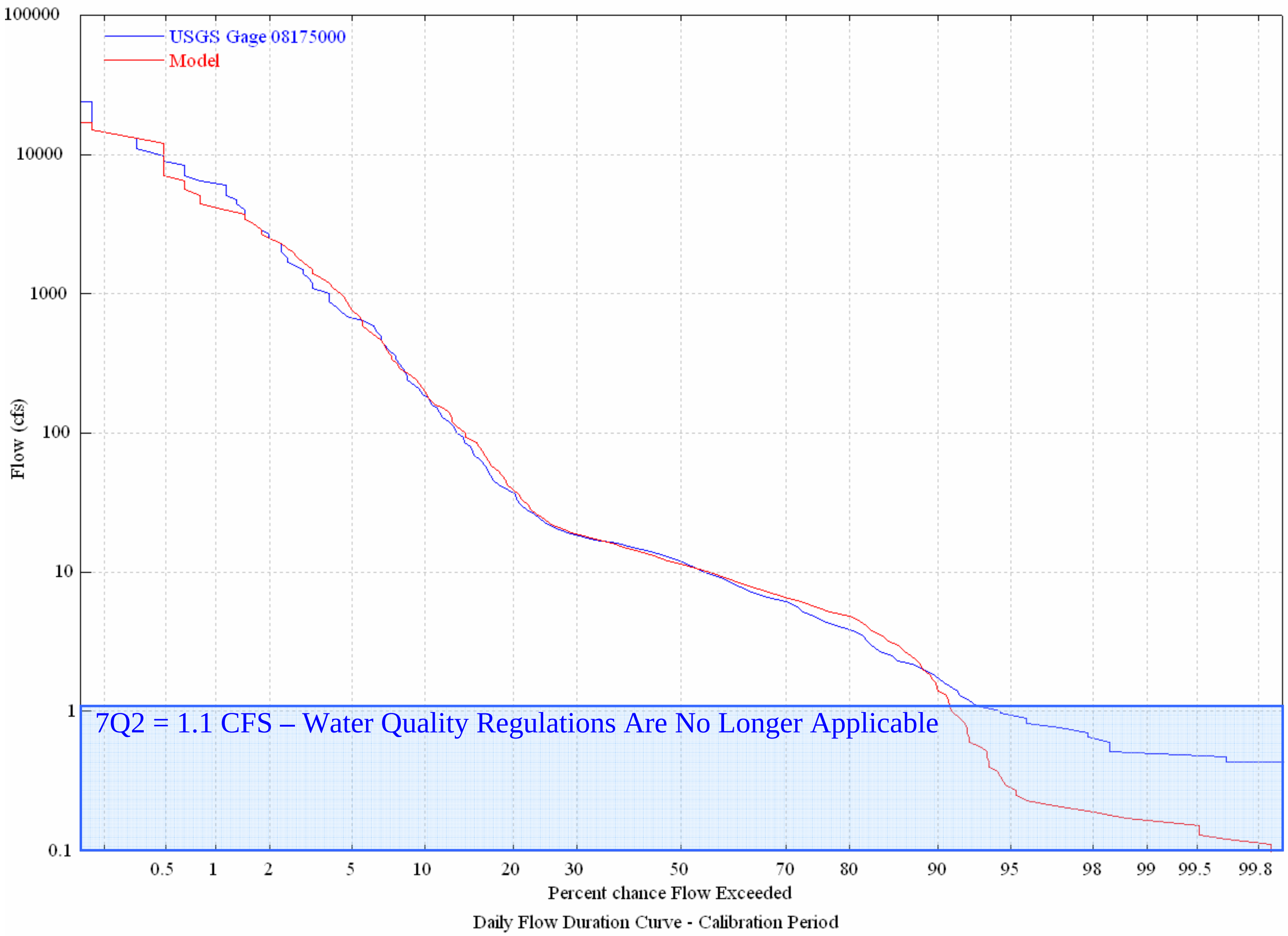


Figure 6.4: Daily Flow Duration Curve - Calibration Period

Chapter 7 Conclusions and Recommendations

There are two main purposes for mathematical modeling. The first is to characterize situations or predict conditions for which no observed data exists. The second is to lend insight into understanding the processes that are important in a system. Modeling for these purposes allows engineers and managers to analyze the factors that affect a system's response and make informed decisions in planning for future conditions.

The overall objective of this project was to develop a watershed model of the Sandies and Elm basin. During the course of the model's development, multiple observations and conclusions were made concerning the structure of Hydrologic Simulation Program – FORTRAN (HSPF), its weaknesses, its strengths, and its future.

7.1 SPATIAL PRECIPITATION DATA FINDINGS

HSPF was chosen because of its ability to simulate non-point pollution discharge from agricultural areas on a continuous time frame. The classic source of precipitation forcing data, the National Climatic Data Center, lacked enough gage precipitation stations with data during the time span required for calibration. Alternate data sources were reviewed as sources of accurate forcing data for the model.

This underlying motivational study uncovered a variety of weaknesses in the precipitation sources currently available. Although precipitation gauging stations, such as those run by the NCDC, are accurate for the point at which they are gauging, they are unable to truly capture the spatial nature of precipitation at their current level of spatial distribution. NEXRAD captures the spatial characteristics of precipitation, but the intensity of storms is not always accurately interpreted. DAYMET, which spatially interpolates daily rain gauge data, also has the same problems as other interpolation methods of point precipitation data in convective, semi-arid, regions, in that it also does not truly capture the spatial nature of rain on the watershed scale.

But, despite the flaws in all of these systems, it is important to note that weather related phenomena are both spatial and temporal in nature, and if the goal of a model is to accurately capture the effects of precipitation on the landscape, it must allow for both aspects of the nature of weather.

7.2 HSPF

Hydrologic Simulation Program – FORTRAN (HSPF) is recommended by the Environmental Protection Agency for hydrologic and water quality watershed process modeling because of its ability to calculate multiple water quality constituents continuously in an unsteady flow environment. These characteristics make HSPF an ideal model for many different types of watersheds across the United States and the world. But, despite these advantages, HSPF does not adapt well to geo-spatial complexity, especially when that complexity comes in the form of precipitation or other meteorological data.

The choice of NEXRAD as the precipitation forcing data was an important factor in the configuration of the HSPF model. HSPF processes are often partitioned to represent an area with homogeneous land use, soil, and topographic characteristics. But, because of the structure of the HSPF model, the entire area represented by an HSPF Operation must also receive uniform forcing data, in this case precipitation. Therefore each area with unique meteorological data must be described by a separate HSPF Operation. The coded structure of HSPF only allows for a total of 500 Operations within one model. This maximum number of Operations limits the ability of HSPF to adapt in a world where the spatial classifications of the physical characteristics in and of a watershed are continuously becoming defined at a higher resolution. Because of this limitation, HSPF is hindered in its ability to advance research in hydrologic modeling given the readily accessible spatial and temporal data now available.

7.3 HSPF FUTURE

The reason for a TMDL study is two-fold. First, it is to substantiate to both the agencies and the stakeholders that the assumption that the problems that have been measured are indeed created by non-point source pollution. Second, it is to persuade the stakeholders that the best management practices suggested are in their best interest and will have an effect to the greater good.

The vision perceived for the future of non-point source pollution water quality modeling is to apply the “raindrop drainage model”, as described in Chapter Four of Arc Hydro: GIS for Water Resources (Maidment, 2002), to parcel level resolution landscape data, so that known factors can be applied.

During the course of this study a survey was conducted of each stakeholder who wished to participate. The survey covered their current number of stock and management and grazing practices. Currently, HSPF only allows this information to be utilized on a percentage basis. For example, the average subbasin in this, rather distributed, HSPF model is 16 square kilometers (approximately 4000 acres). The majority of the farms in the area are between 50 and 100 acres. (USDA: NASS, 2005) This data can only be applied, in the current HSPF format, as an average across the subbasin. The ability to apply this type of information accurately would improve modeling capabilities and provide better direct correlation between individual agricultural practices and water quality. A rancher, who can visually see the connection between the density of animals and practice effects per parcel in his area to the level of river pollution in that same area, may be more willing to undertake the suggested best management practices.

To this end, GIS should take an even greater role in the future of watershed modeling than it currently does. GIS is currently used to provide the data information on the front end and sometimes the output information on the back end, but during the intervening time the information is taken out of the GIS environment and placed in a computer program with no real spatial interpretation of the data. This creates a model in which a great many parameters are lumped together due to the nature of the program.

The development of GIS and the spatial data that has become and is continuing to become available has induced an environment for watershed hydrologic modeling which justifies model restructuring. The true spatial interactions in nature should be taken into account in modeling. A watershed is defined, not only by it land use, but also by its place in the world. The climate, soils, topography, and history all combine to create an extremely varied and unique watershed character. No lumped model could truly represent a watershed in all its complexities. The spatial differences that define one watershed from another also define that watershed's response to precipitation, land use changes, and pollution. To truly understand the consequences of decisions and environmental changes made in a watershed on the ecosystem, a more complete understanding of the processes and interactions in nature must be undertaken. The recent progress in the spatial resolution of the characteristic composition of a watershed has allowed water resource scientist and engineers to begin to understand the changes in a watershed's response to anthropogenic and climatological changes.

The study of the physical world has been transformed through the use of Geographic Information Systems. It has enhanced analysis of hydrologic systems by allowing more detailed representation and modeling of topography, soils, and vegetative data. GIS can display many things in great physical detail, for example a 1-second DEM grid displays elevations at more than 1,000 locations per square kilometer. This increased level of detail encourages the idea that simulating at a million points in a watershed is better than at a few hundred or a thousand locations. This is too simplistic. (HydroComp, 2006a)

The accuracy of a model depends on many things: knowledge of the underlying processes, accurate as well as precise data, and a modeler's skill and experience in calibrating model parameters from available watershed data. But, what it should not depend on is the limits of the modeling program.

The new spatially defined model should be, in essence, a digital watershed. It should be created as multiple layers that have interactive processes in and between themselves. First, an atmospheric layer that is composed of precipitation, evaporation, temperature, wind, cloud cover, and moisture content should act as the topmost forcing layer. Second, the land surface layer made up of parcels, land use, vegetation, topography, and surface water will be the layer in which human and nature interact. Third is the sub-terrain layer, in which the archives of the history of the watershed are kept, will encompass the soils, water table, aquifers, and bedrock.

Within this layered system would be a storehouse for the development of the myriad of relationships and processes that occur between the layers. I foresee one day not only gaining an understanding on the response of a watershed to the weather, but also achieving a much greater knowledge and appreciation of the effects that changes in the watershed has on the climate.

7.4 A Word of Caution

The use of detailed spatial information could lend an element of precision that is not real and dupe an unwary modeler into an overconfidence in the robustness of the model. A model is only as good as its individual parts. There is incredible complexity in nature; the interactions within Her are so amazing as to appear simple in their beauty.

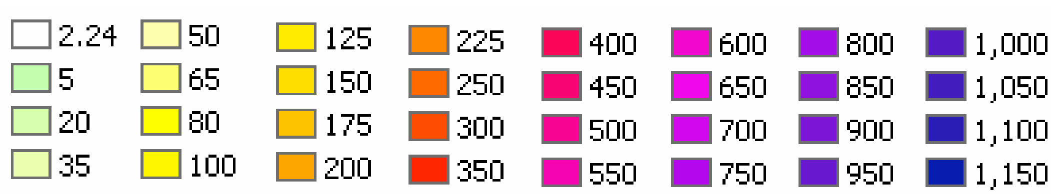
These spatial improvements in modeling are suggested not because they are, in any way, more accurate than the lumped models available today, but rather, because they will highlight the gaps in our knowledge and allow for advances in learning about the complex process and spatial interactions of nature.

Appendix A: Convective Set Spatial Interpretation of Precipitation

JANUARY 27, 2000

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	5.2 cfs	Day After:	27.9 cfs
NEXRAD	Minimum:	0.11 in.	Maximum:	1.35 in.
NCDC	Minimum:	0.12 in.	Maximum:	0.76 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

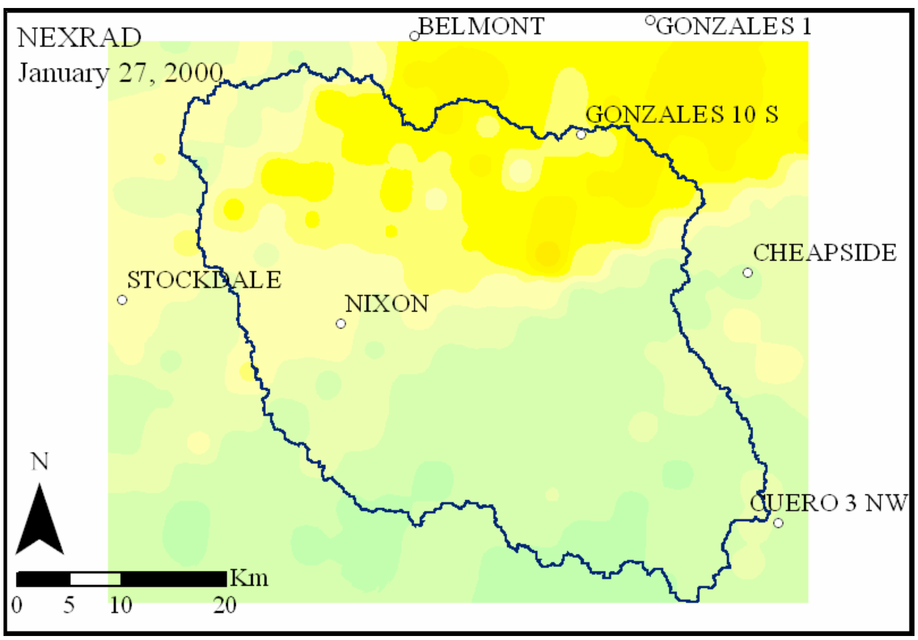


Figure A.1: NEXRAD January 27, 2000

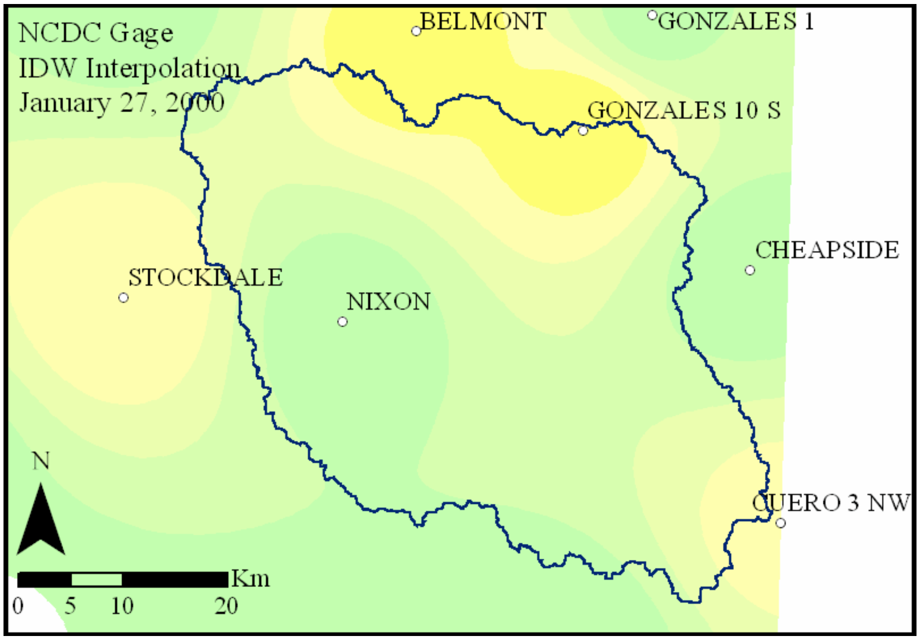


Figure A.2: NCDC Gage IDW Interpolation January 27, 2000

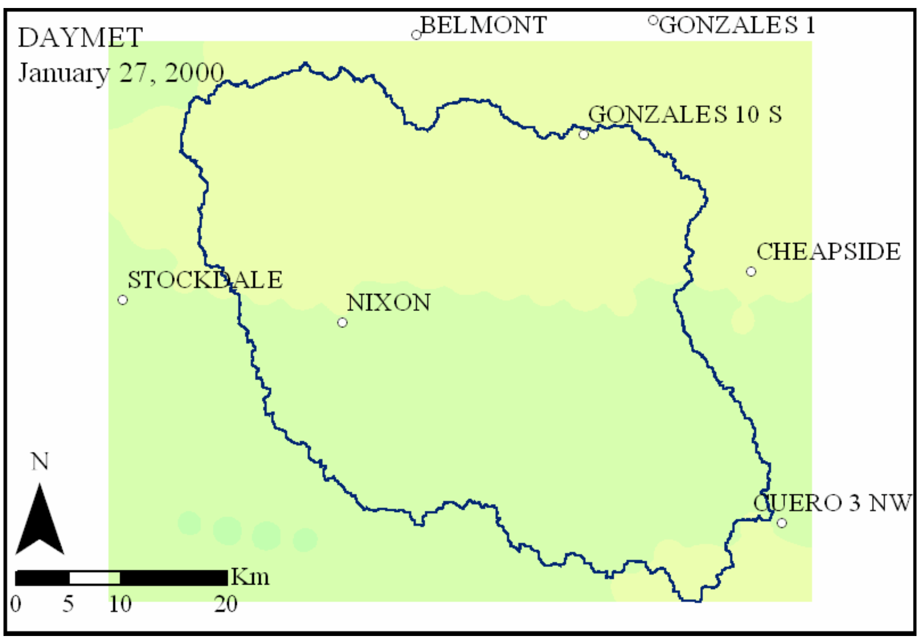
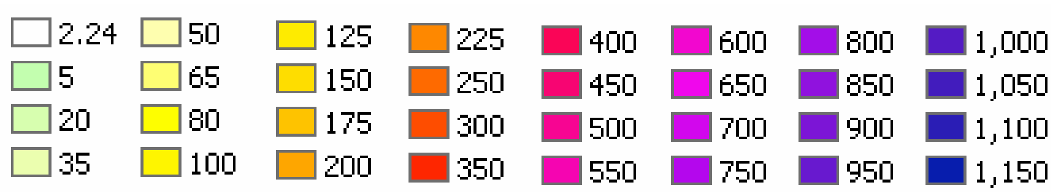


Figure A.3: DAYMET Gage Interpolation January 27, 2000

FEBRUARY 23, 2000

NCDC Missing Stations: Kingsbury and New Braunfels Municipal AP

USGS Gage Flow	Day Before:	6.2 cfs	Day After:	214 cfs
NEXRAD	Minimum:	0.28 in.	Maximum:	2.98 in.
NCDC	Minimum:	0 in.	Maximum:	2.16 in.
Convective Cells:	Number:	2	Size:	10 km.



Scale (hundredth inch)

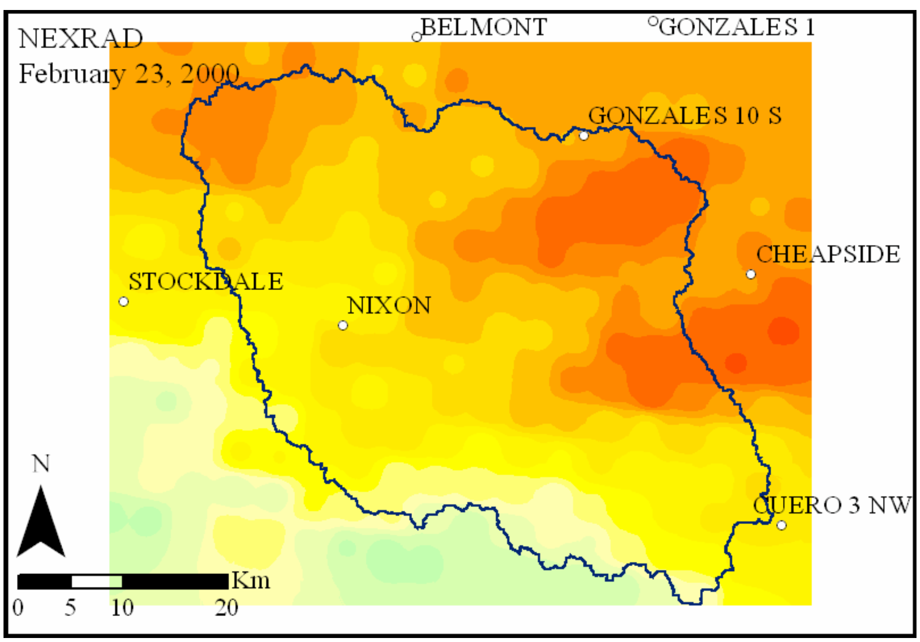


Figure A.4: NEXRAD February 23, 2000

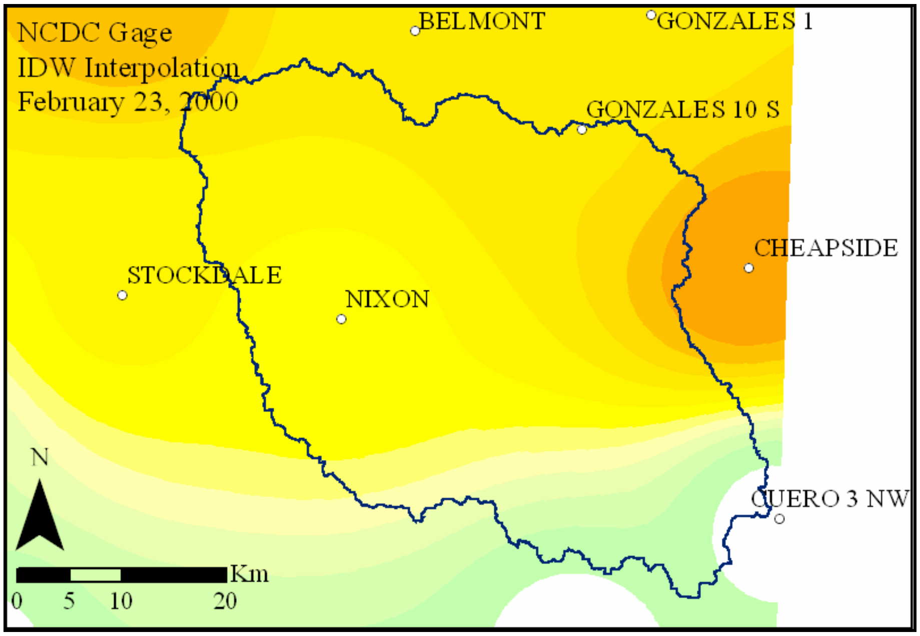


Figure A.5: NCDC Gage IDW Interpolation February 23, 2000

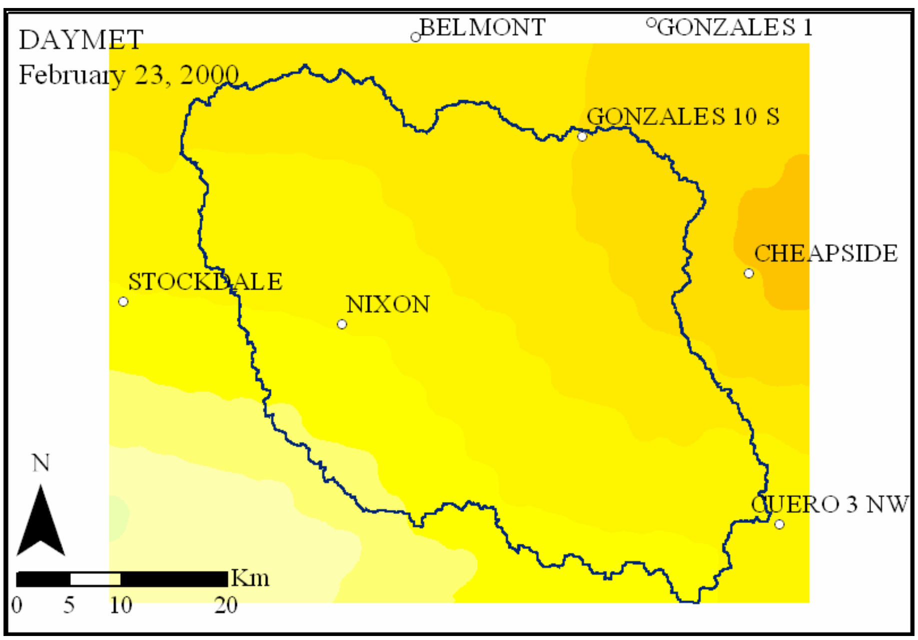
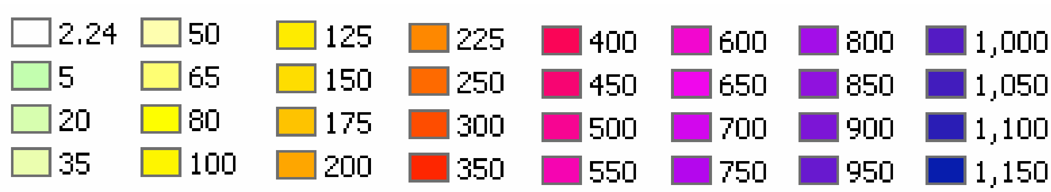


Figure A.6: DAYMET Gage Interpolation February 23, 2000

MARCH 11, 2000

NCDC Missing Stations: Kingsbury and New Braunfels Municipal AP

USGS Gage Flow	Day Before:	6.1 cfs	Day After:	20 cfs
NEXRAD	Minimum:	0 in.	Maximum:	5.2 in.
NCDC	Minimum:	0 in.	Maximum:	0.18 in.
Convective Cells:	Number:	1	Size:	10 km.



Scale (hundredth inch)

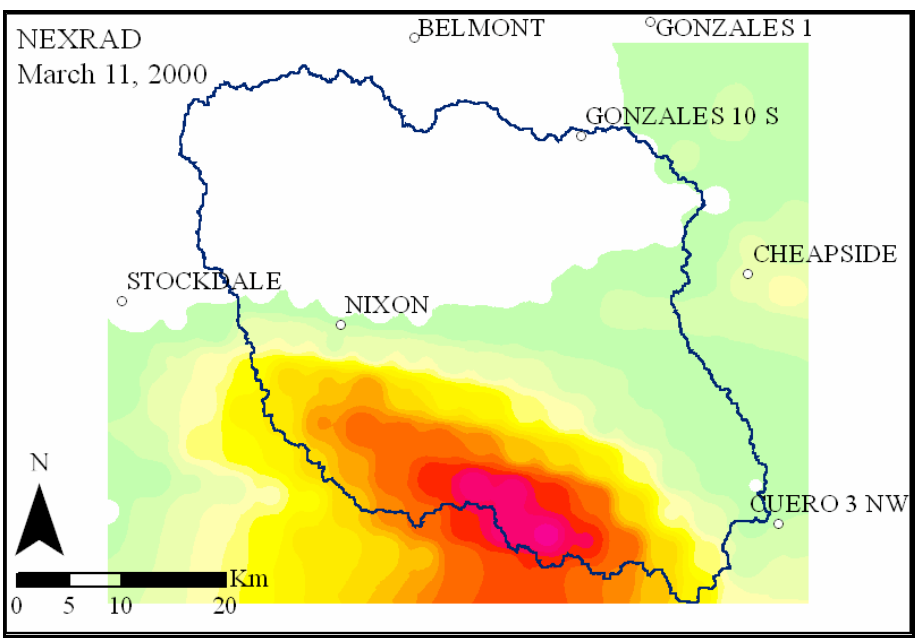


Figure A.7: NEXRAD March 11, 2000

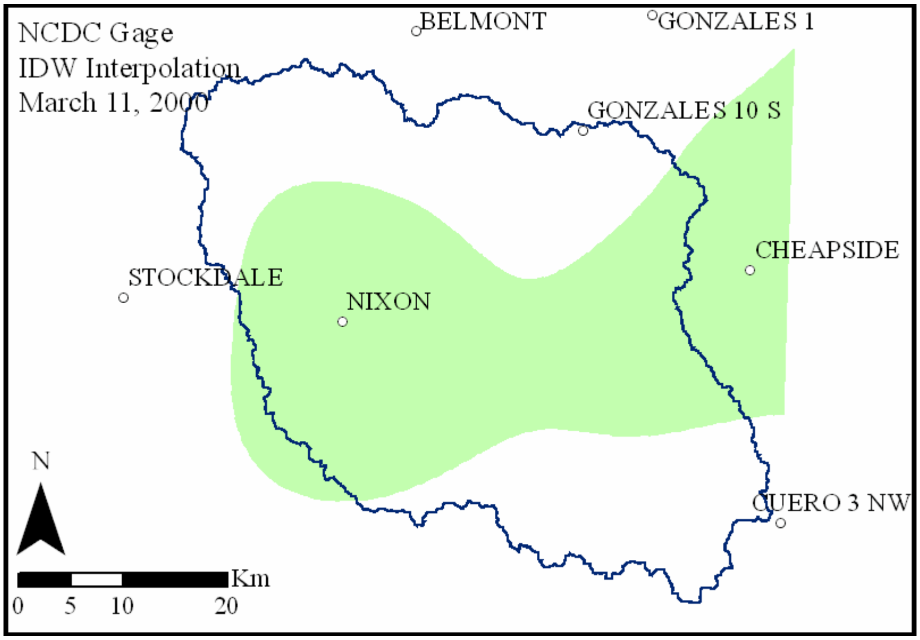


Figure A.8: NCDC Gage IDW Interpolation March 11, 2000

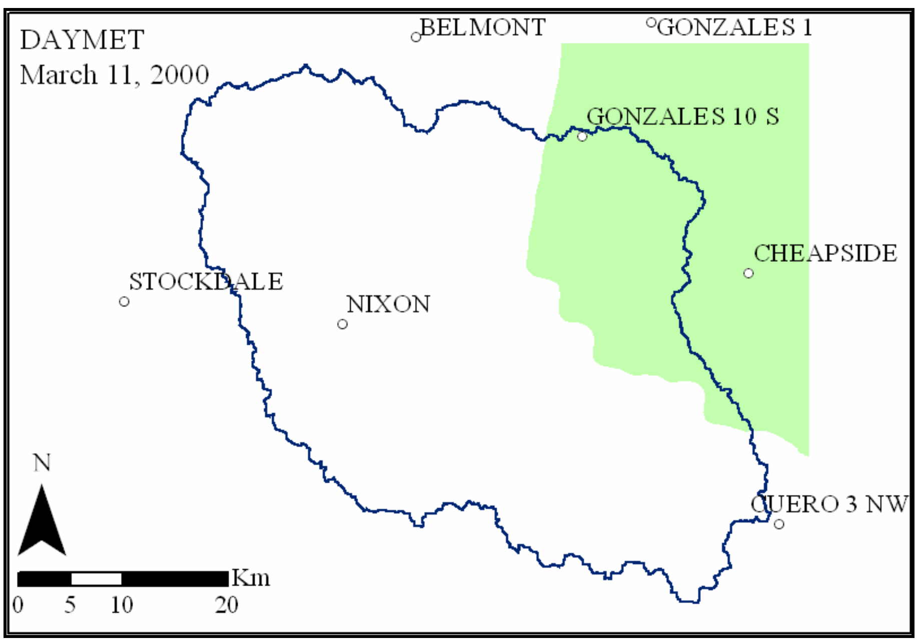
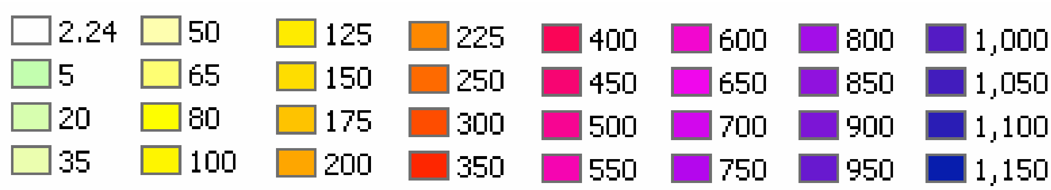


Figure A.9: DAYMET Gage Interpolation March 11, 2000

APRIL 23, 2001

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	9.8 cfs	Day After:	26 cfs
NEXRAD	Minimum:	0.15 in.	Maximum:	3.29 in.
NCDC	Minimum:	0 in.	Maximum:	2.04 in.
Convective Cells:	Number:	3	Size:	5 km.



Scale (hundredth inch)

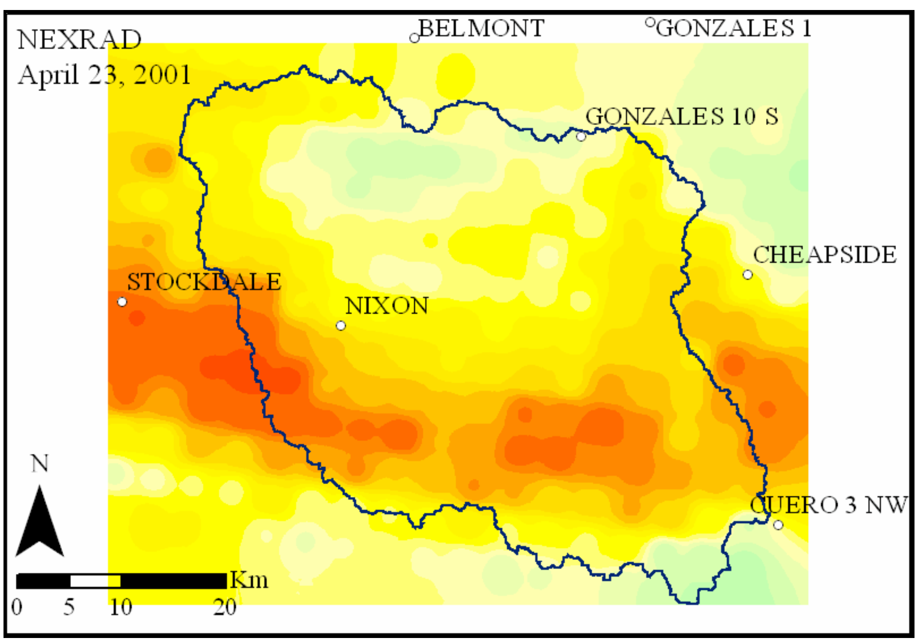


Figure A.10: NEXRAD April 23, 2001

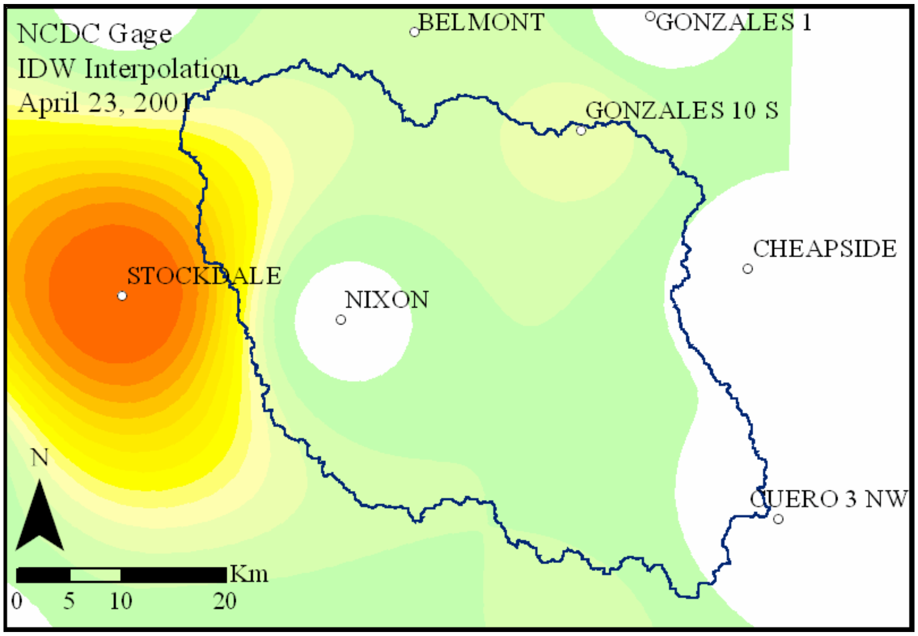


Figure A.11: NCDC Gage IDW Interpolation April 23, 2001

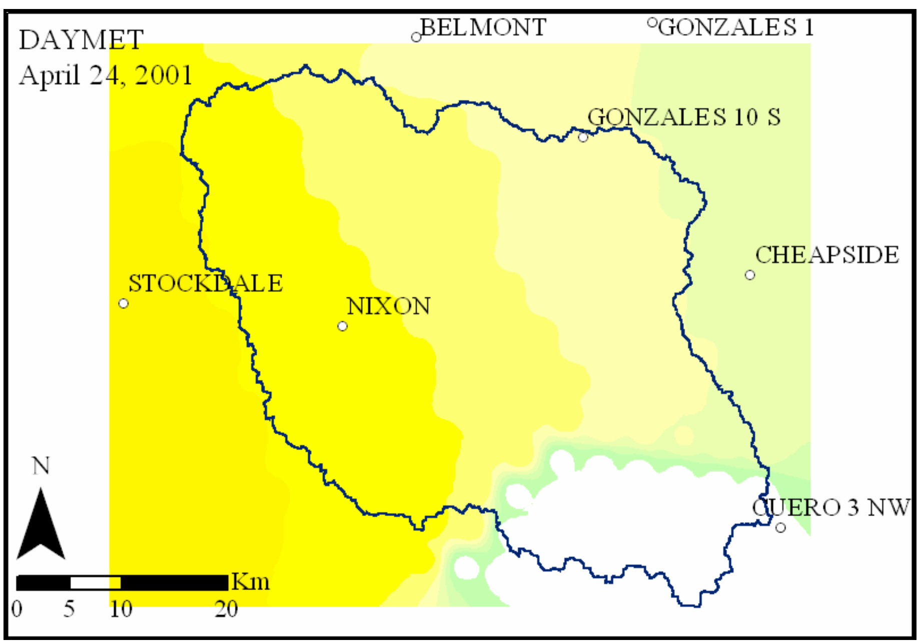
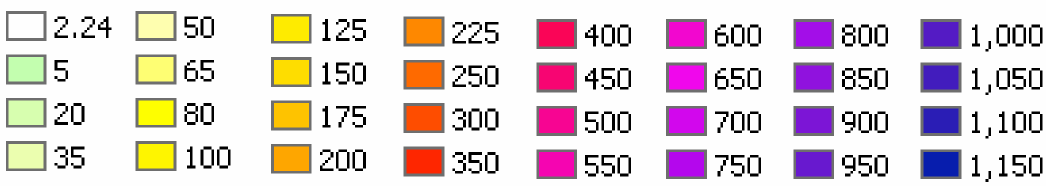


Figure A.12: DAYMET Gage Interpolation April 24, 2001

DAYMET showed no rain for April 23, 2001. April 24, 2001 is shown instead.

MAY 13, 2004

NCDC Missing Stations:	Nixon			
USGS Gage Flow	Day Before:	33 cfs	Day After:	640 cfs
NEXRAD	Minimum:	0 in.	Maximum:	2.16 in.
NCDC	Minimum:	0 in.	Maximum:	1.64 in.
Convective Cells:	Number:	1	Size:	10 km.



Scale (hundredth inch)

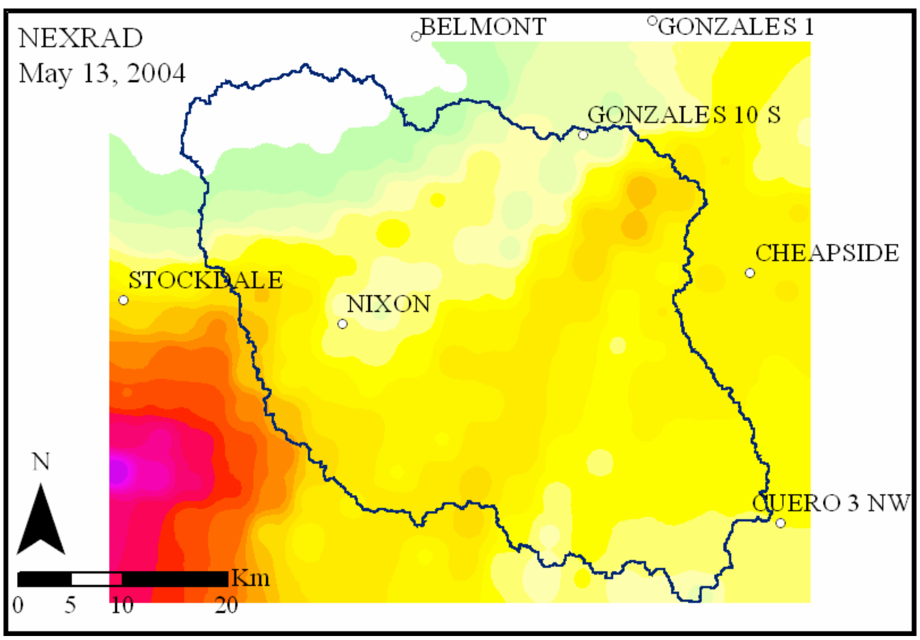


Figure A.13: NEXRAD May 13, 2004

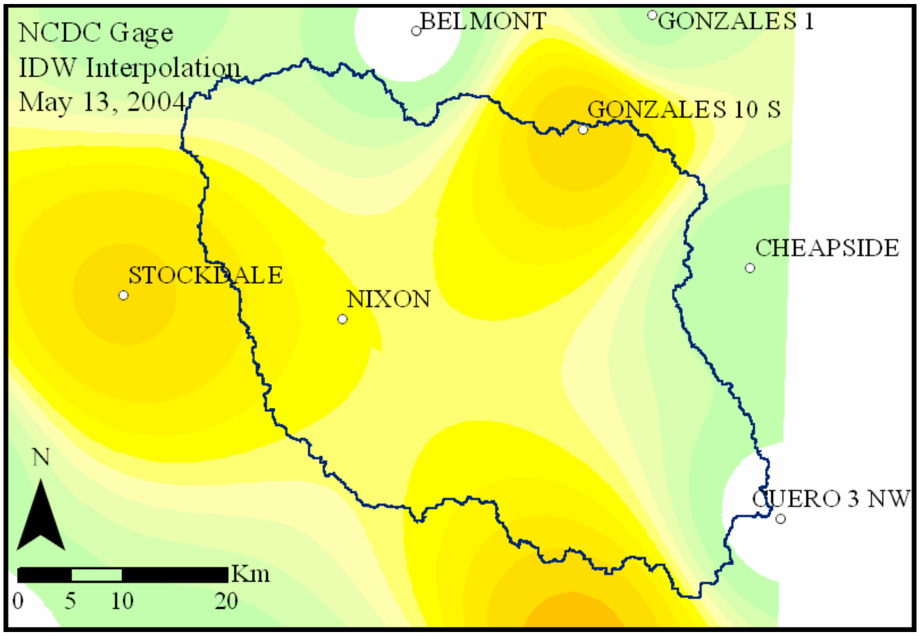


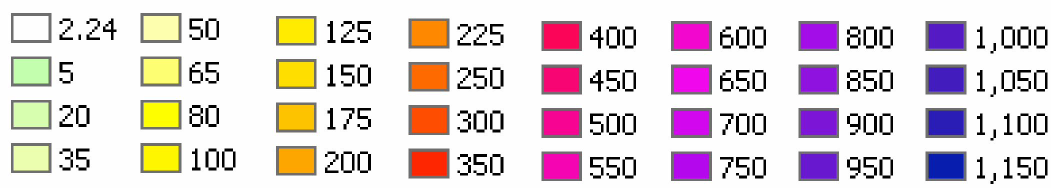
Figure A.14: NCDC Gage IDW Interpolation May 13, 2004

DAYMET data is not available for 2004.

JUNE 10, 2000

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	39 cfs	Day After:	420 cfs
NEXRAD	Minimum:	0.88 in.	Maximum:	5.5 in.
NCDC	Minimum:	0.58 in.	Maximum:	2.85 in.
Convective Cells:	Number:	2	Size:	10 km.



Scale (hundredth inch)

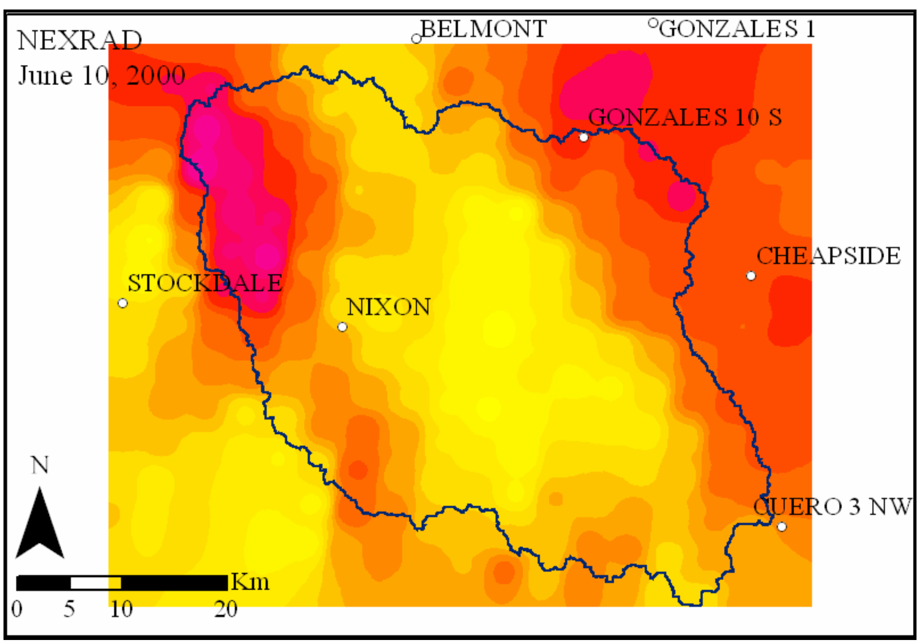


Figure A.16: NEXRAD June 10, 2000

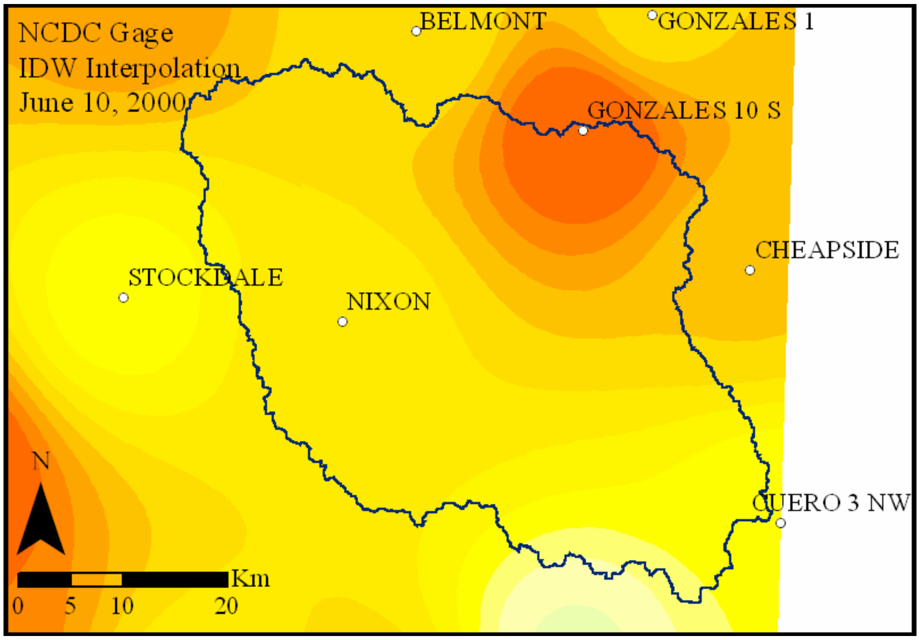


Figure A.17: NCDC Gage IDW Interpolation June 10, 2000

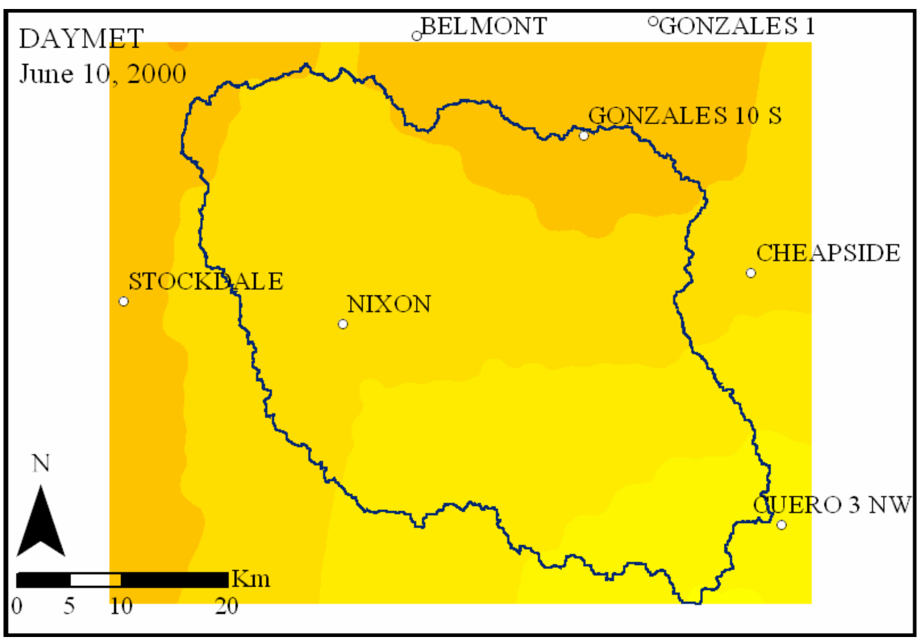
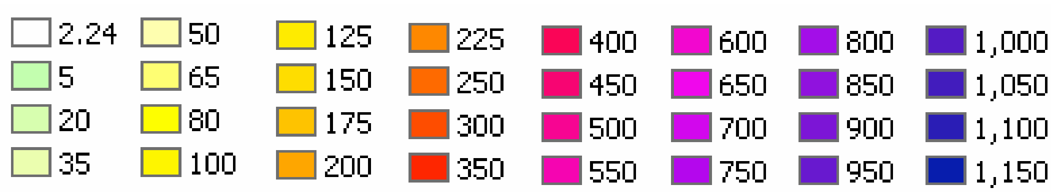


Figure A.18: DAYMET Gage Interpolation June 10, 2000

JULY 31, 2000

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	1.8 cfs	Day After:	1.7 cfs
NEXRAD	Minimum:	0 in.	Maximum:	2.92 in.
NCDC	Minimum:	0 in.	Maximum:	0.08 in.
Convective Cells:	Number:	26	Size:	5 km.



Scale (hundredth inch)

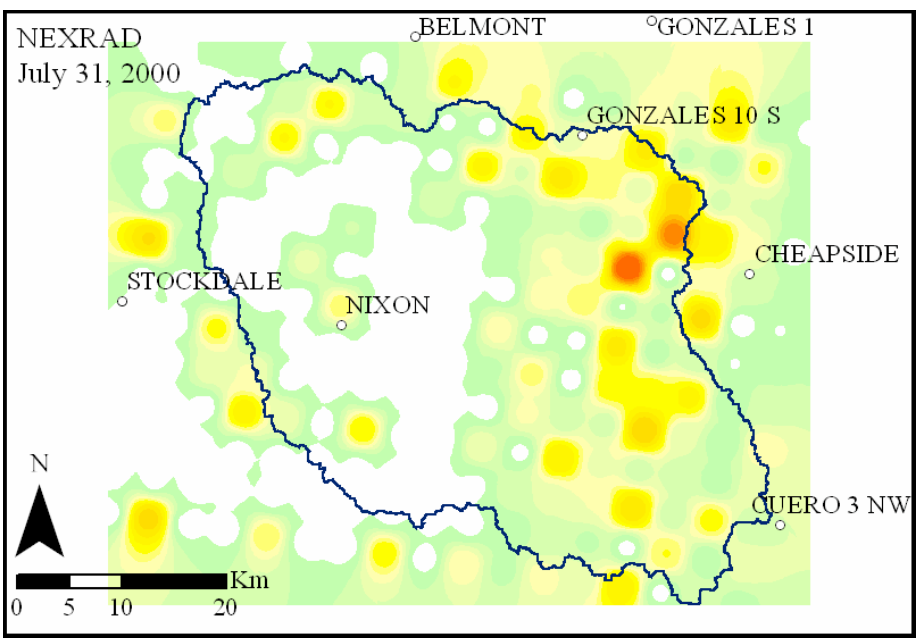


Figure A.19: NEXRAD July 31, 2000

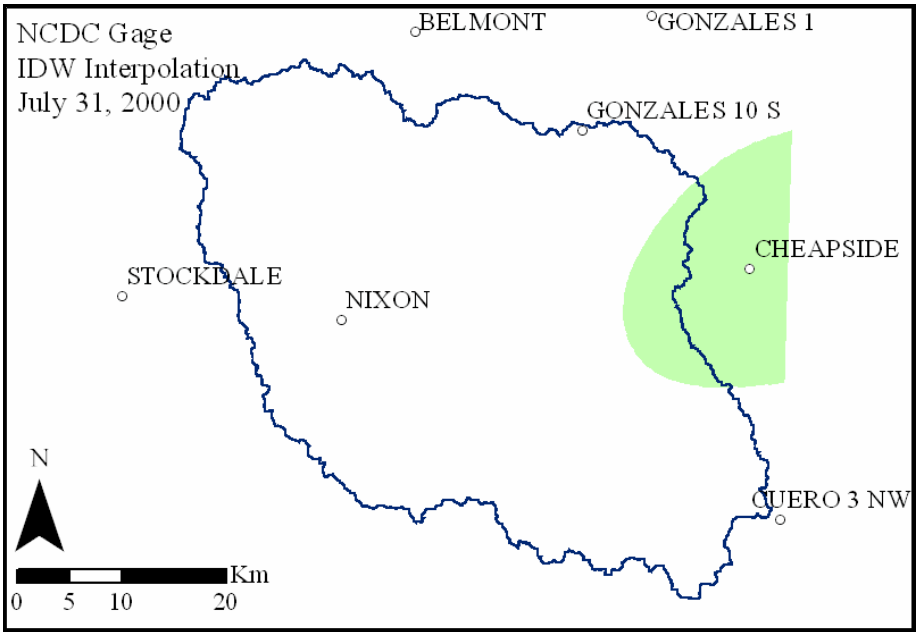


Figure A.20: NCDC Gage IDW Interpolation July 31, 2000

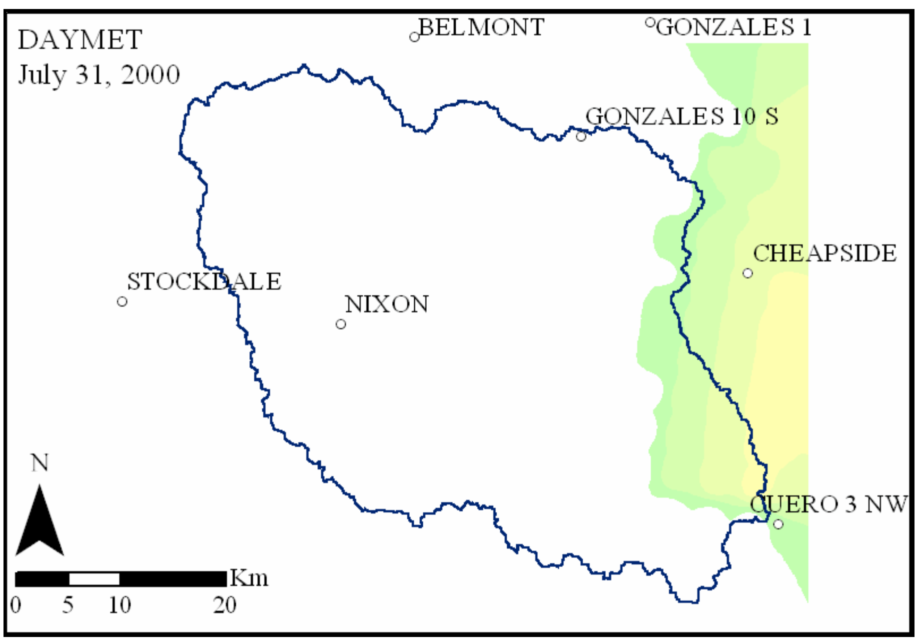
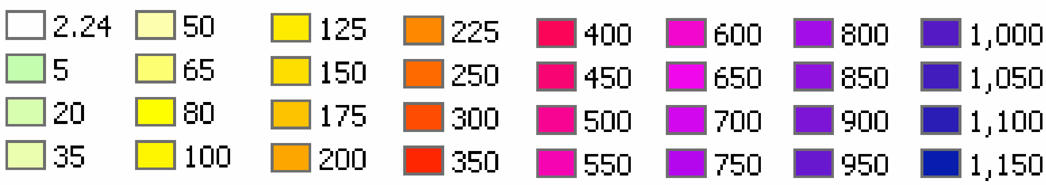


Figure A.21: DAYMET Gage Interpolation July 31, 2000

AUGUST 31, 2001

NCDC Missing Stations:	Falls City 4WNW, Karnes City, and New Braunfels MAP			
USGS Gage Flow	Day Before:	174 cfs	Day After:	25,900 cfs
NEXRAD	Minimum:	0.77 in.	Maximum:	9.17 in.
NCDC	Minimum:	0.32 in.	Maximum:	8.3 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

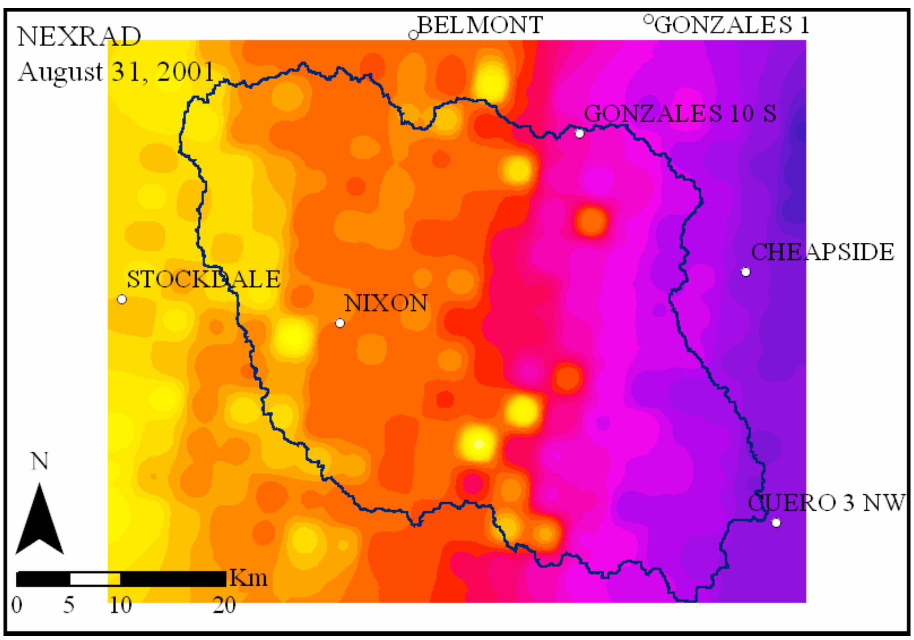


Figure A.22: NEXRAD August 31, 2001

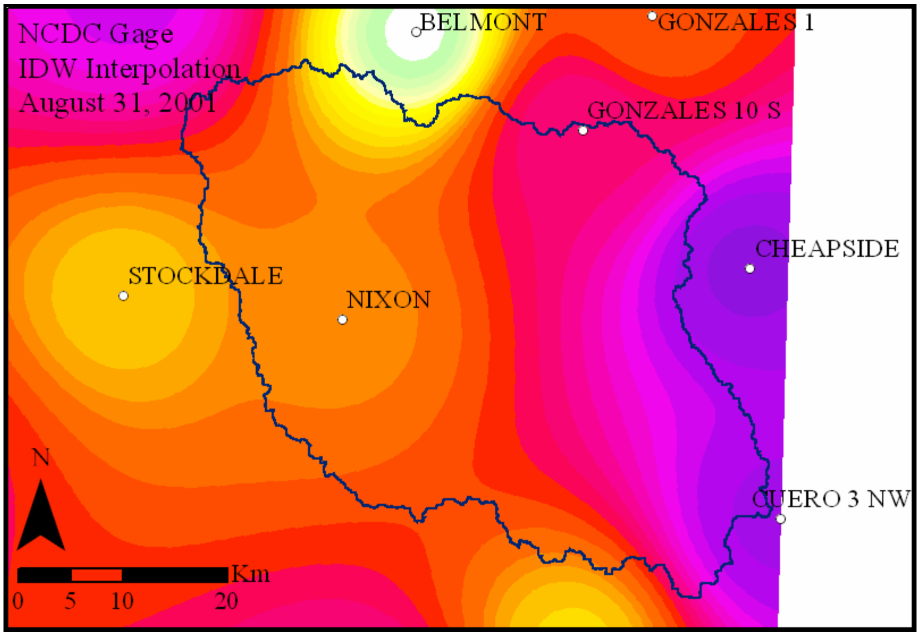


Figure A.23: NCDC Gage IDW Interpolation August 31, 2001

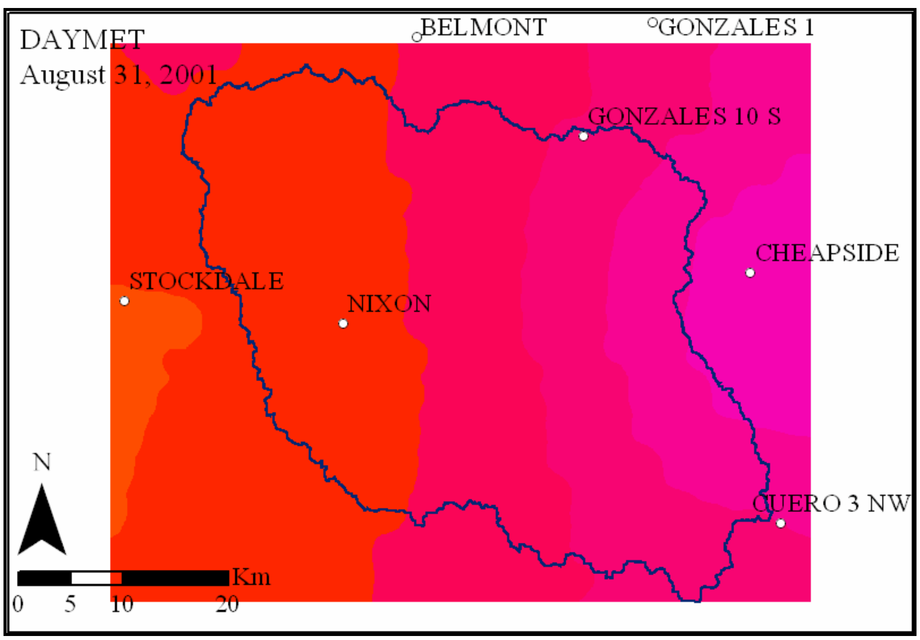
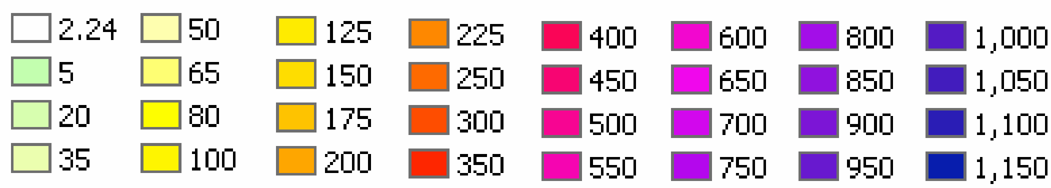


Figure A.24: DAYMET Gage Interpolation August 31, 2001

SEPTEMBER 22, 2001

NCDC Missing Stations:	Falls City 4WNW, Karnes City, and New Braunfels MAP			
USGS Gage Flow	Day Before:	21 cfs	Day After:	18 cfs
NEXRAD	Minimum:	0 in.	Maximum:	1.72 in.
NCDC	Minimum:	0.02 in.	Maximum:	0.75 in.
Convective Cells:	Number:	1	Size:	10 km.



Scale (hundredth inch)

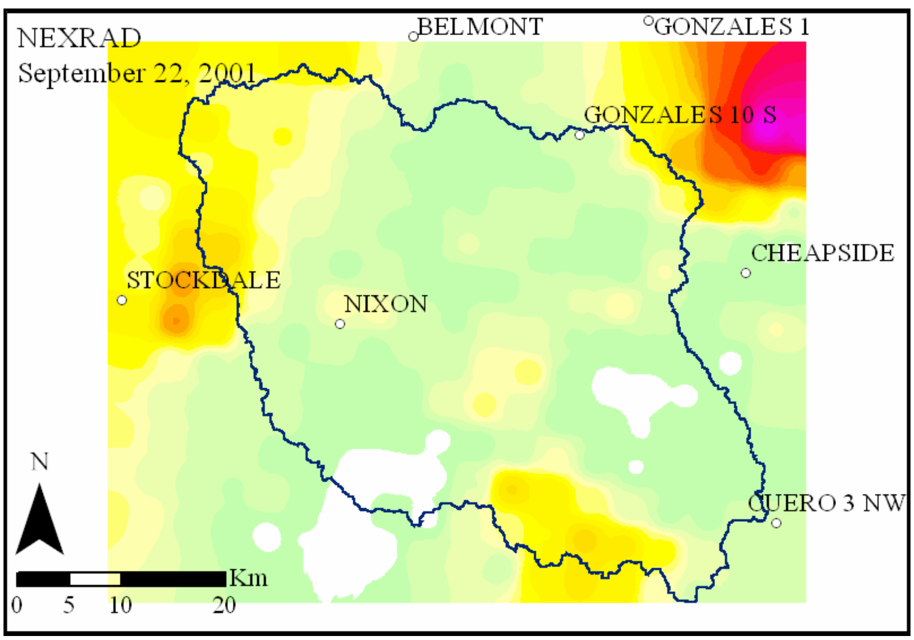


Figure A.25: NEXRAD September 22, 2001

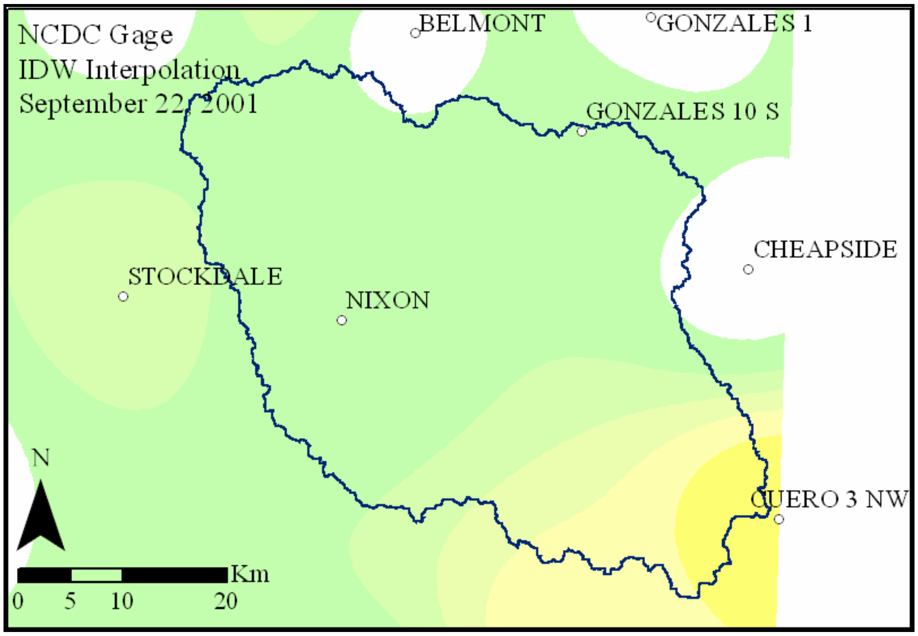


Figure A.26: NCDC Gage IDW Interpolation September 22, 2001

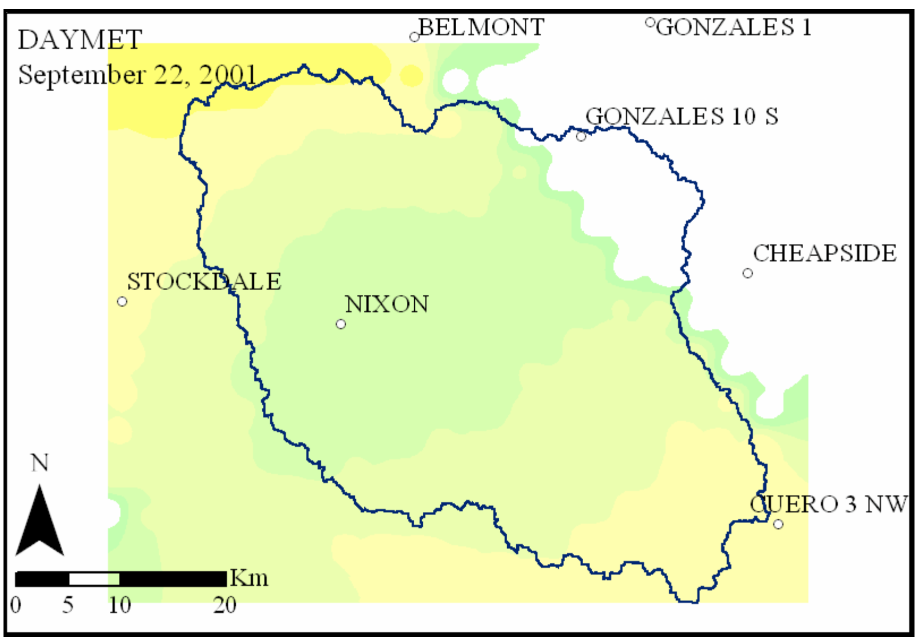
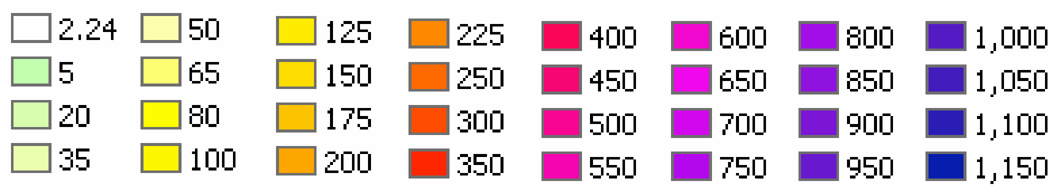


Figure A.27: DAYMET Gage Interpolation September 22, 2001

OCTOBER 25, 2003

NCDC Missing Stations: Nixon

USGS Gage Flow	Day Before:	5 cfs	Day After:	15 cfs
NEXRAD	Minimum:	0 in.	Maximum:	4.47 in.
NCDC	Minimum:	0 in.	Maximum:	0 in.
Convective Cells:	Number:	1	Size:	5 km.



Scale (hundredth inch)

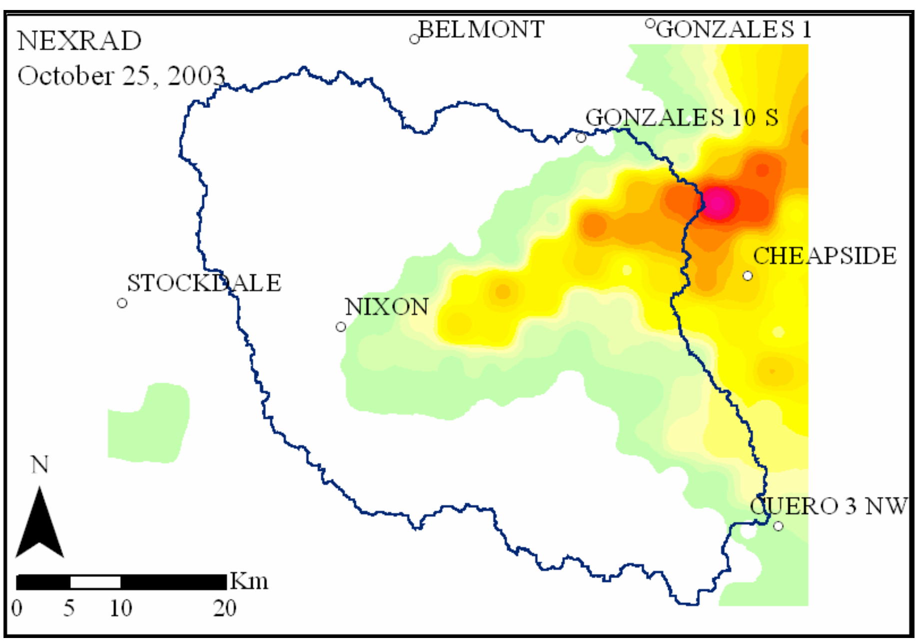


Figure A.28: NEXRAD October 25, 2003

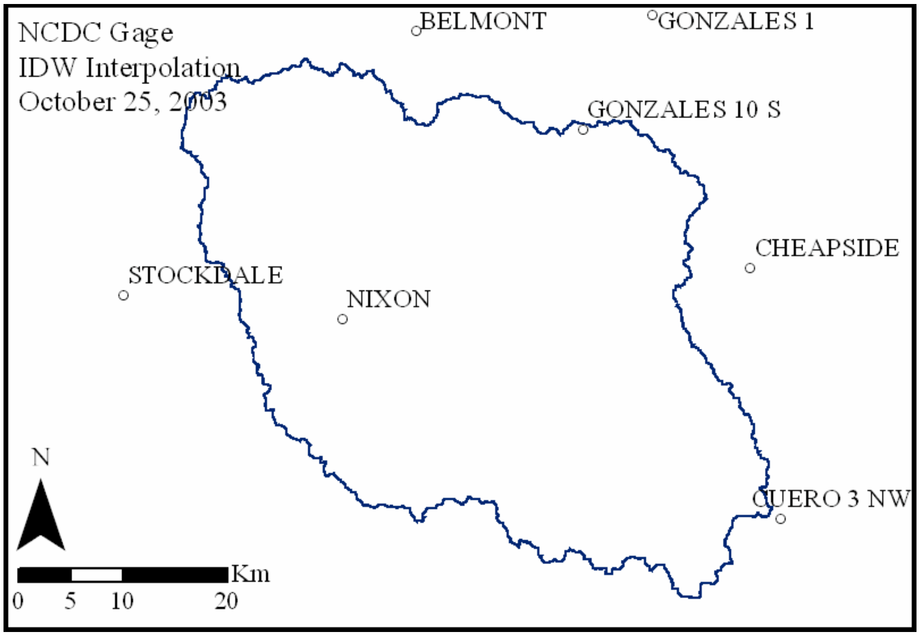


Figure A.29: NCDC Gage IDW Interpolation October 25, 2003

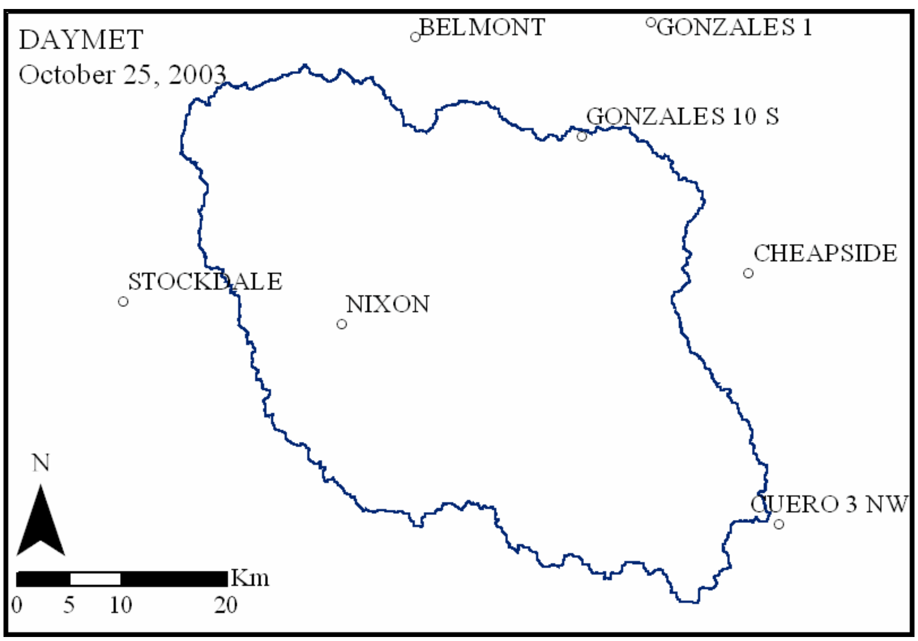
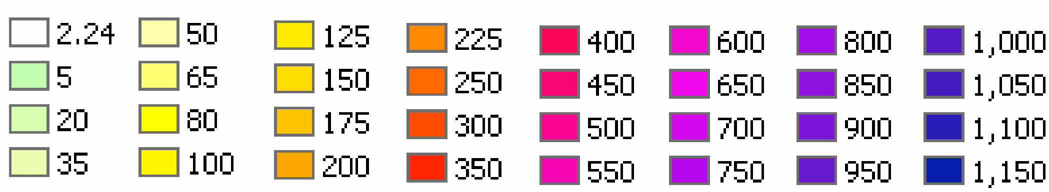


Figure A.30: DAYMET Gage Interpolation October 25, 2003

NOVEMBER 17, 2003

NCDC Missing Stations: Nixon

USGS Gage Flow	Day Before:	6.8 cfs	Day After:	8.5 cfs
NEXRAD	Minimum:	0.13 in.	Maximum:	4.0 in.
NCDC	Minimum:	0.03 in.	Maximum:	5.3 in.
Convective Cells:	Number:	1	Size:	10 km.



Scale (hundredth inch)

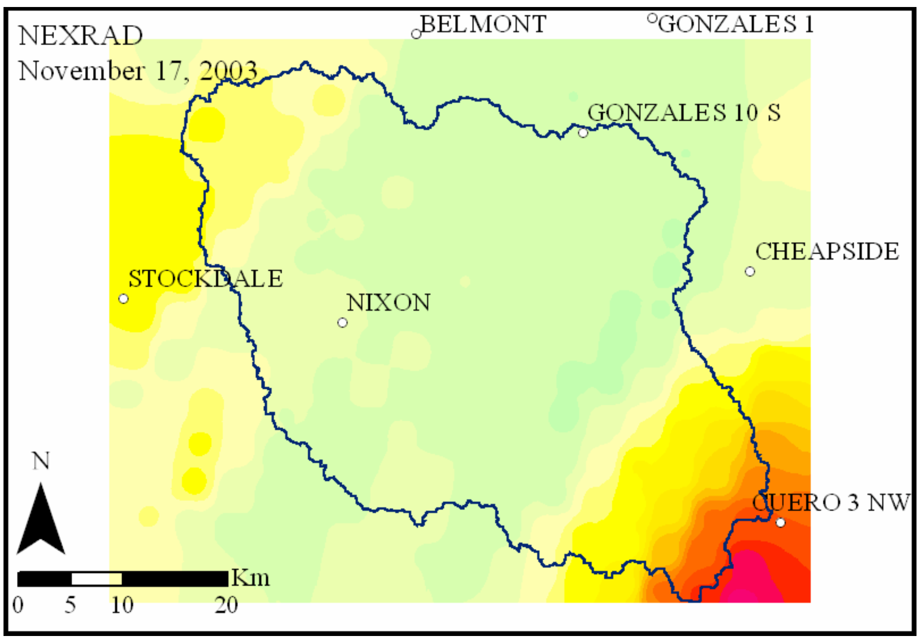


Figure A.31: NEXRAD November 17, 2003

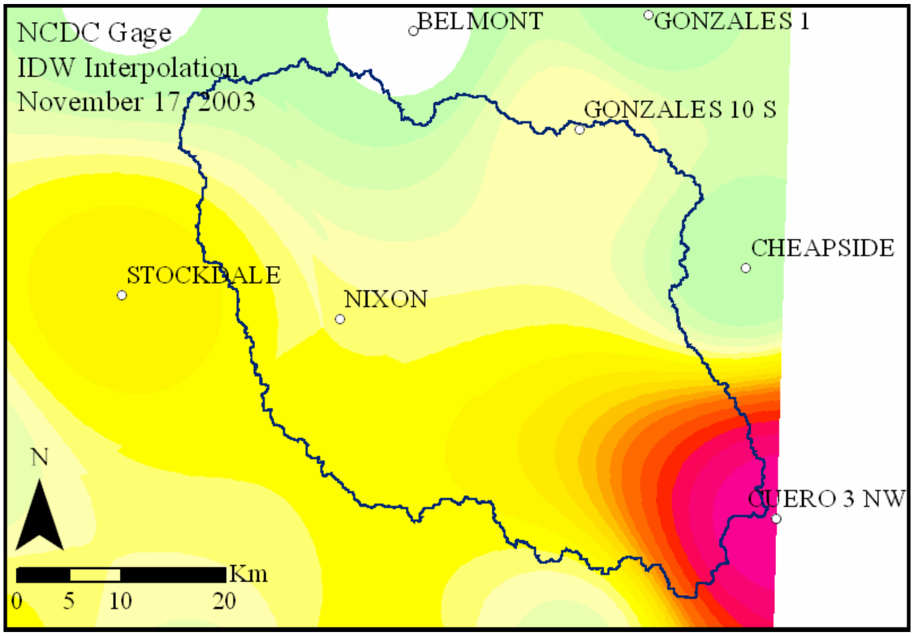


Figure A.32: NCDC Gage IDW Interpolation November 17, 2003

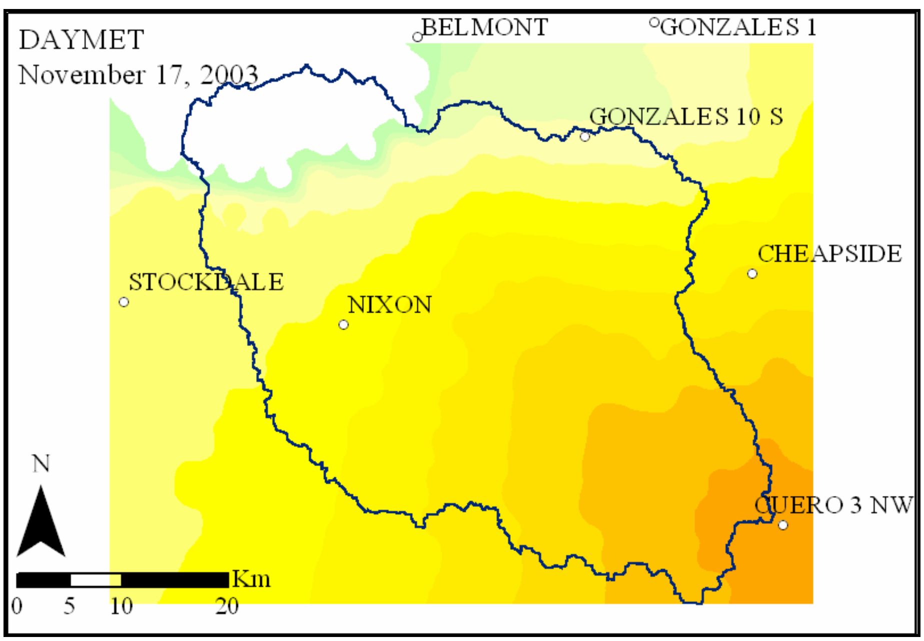
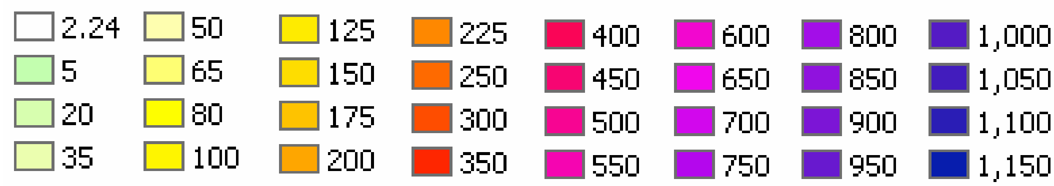


Figure A.33: DAYMET Gage Interpolation November 17, 2003

DECEMBER 12, 2002

NCDC Missing Stations: Nixon

USGS Gage Flow	Day Before:	1050 cfs	Day After:	1780 cfs
NEXRAD	Minimum:	0.26 in.	Maximum:	3.71 in.
NCDC	Minimum:	0 in.	Maximum:	1.8 in.
Convective Cells:	Number:	1	Size:	5 km.



Scale (hundredth inch)

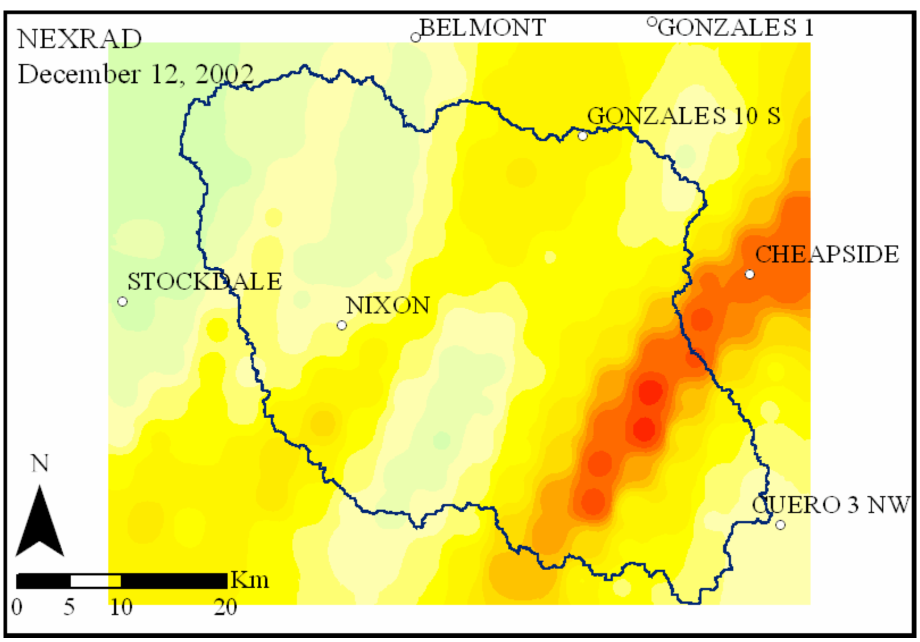


Figure A.34: NEXRAD December 12, 2002

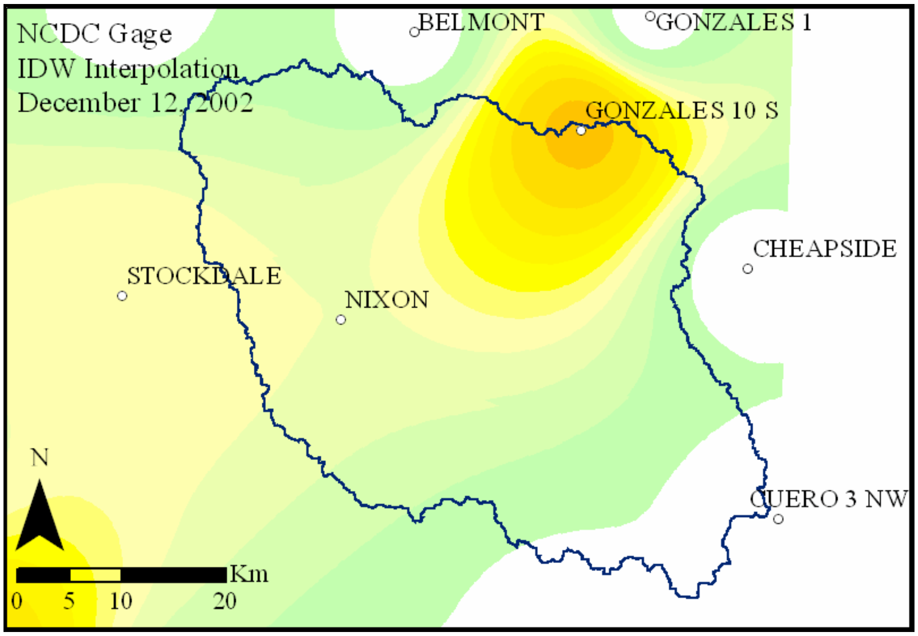


Figure A.35: NCDC Gage IDW Interpolation December 12, 2002

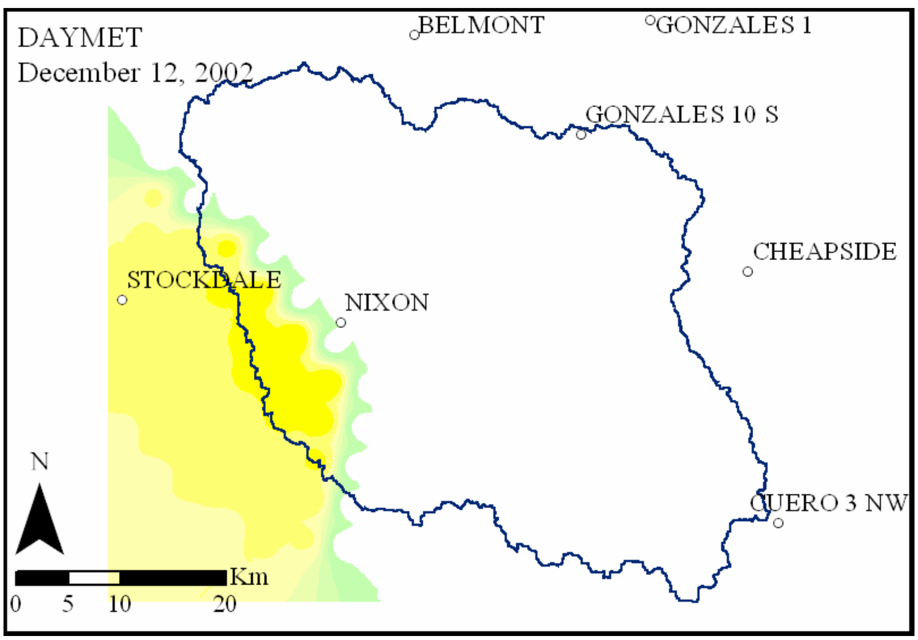


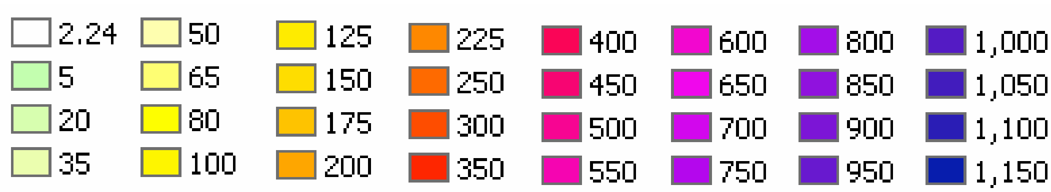
Figure A.36: DAYMET Gage Interpolation December 12, 2002

Appendix B: Frontal Storm Set Spatial Interpretation of Precipitation

JANUARY 7, 2000

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	4.4 cfs	Day After:	37 cfs
NEXRAD	Minimum:	0.36 in.	Maximum:	1.85 in.
NCDC	Minimum:	0.63 in.	Maximum:	3.32 in.
Convective Cells:	Number:	2	Size:	5 Km



Scale (hundredth inch)

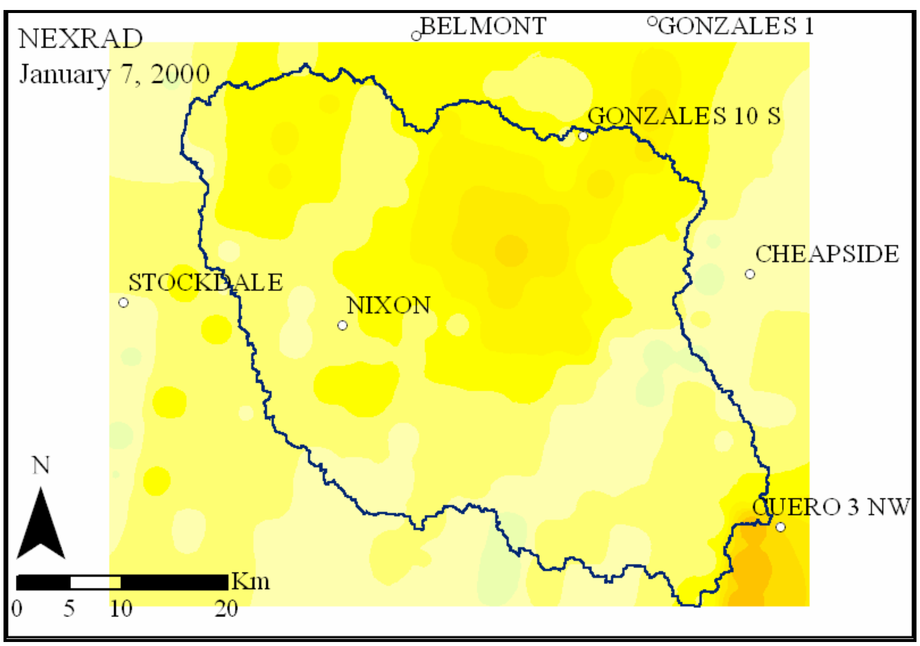


Figure B.1: NEXRAD January 7, 2000

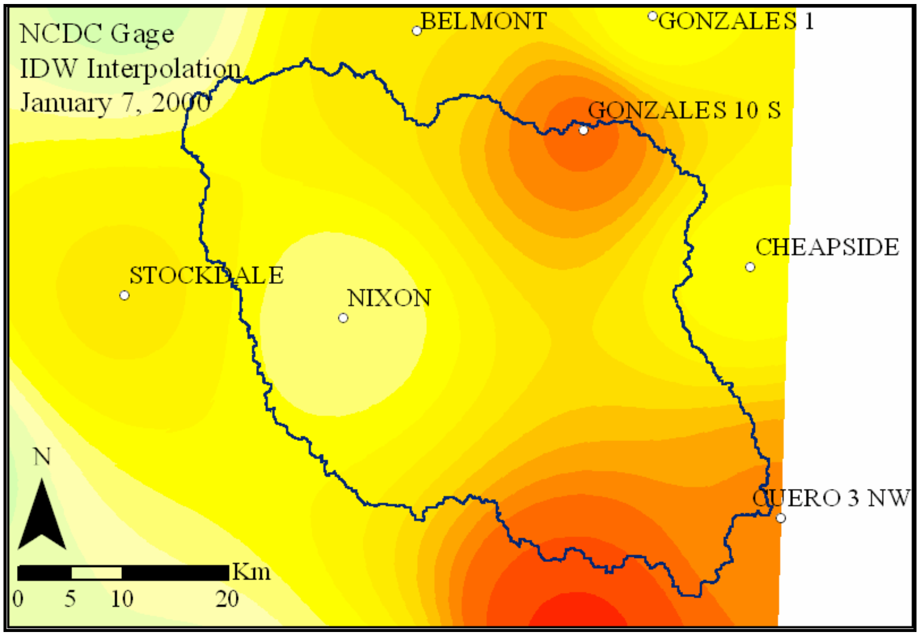


Figure B.2: NCDC Gage IDW Interpolation January 7, 2000

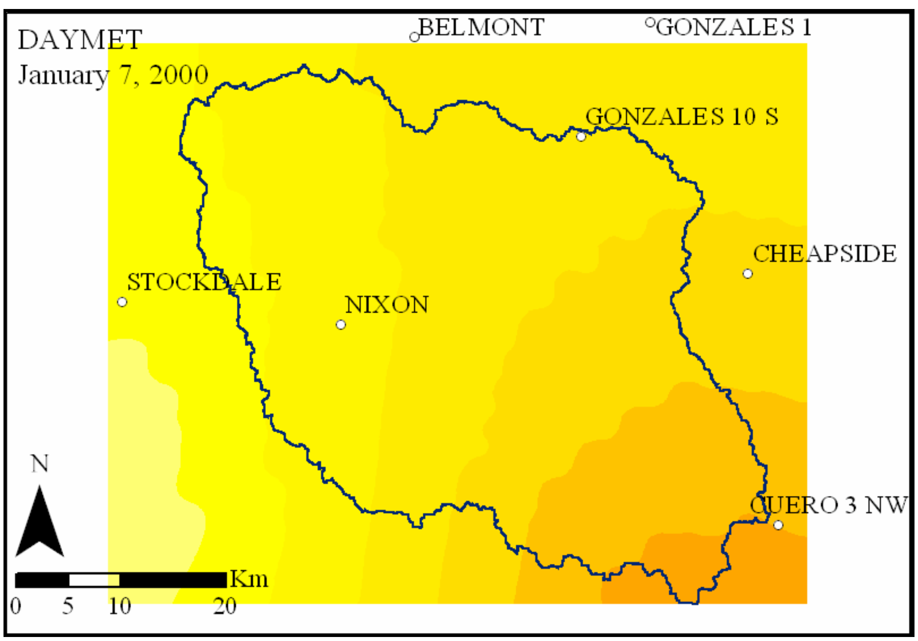
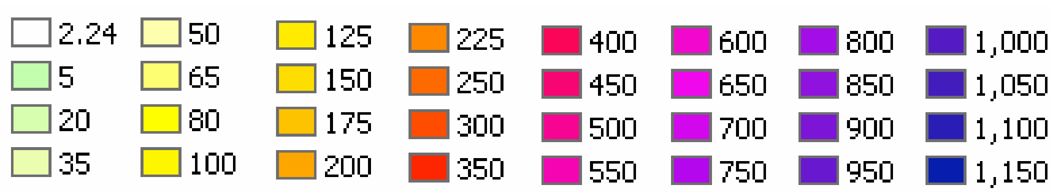


Figure B.3: DAYMET Gage Interpolation January 7, 2000

FEBRUARY 21, 2003

NCDC Missing Stations: Gonzales 10 SW and Nixon

USGS Gage Flow	Day Before:	219 cfs	Day After:	2460 cfs
NEXRAD	Minimum:	0 in.	Maximum:	0.34 in.
NCDC	Minimum:	0 in.	Maximum:	1.98 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

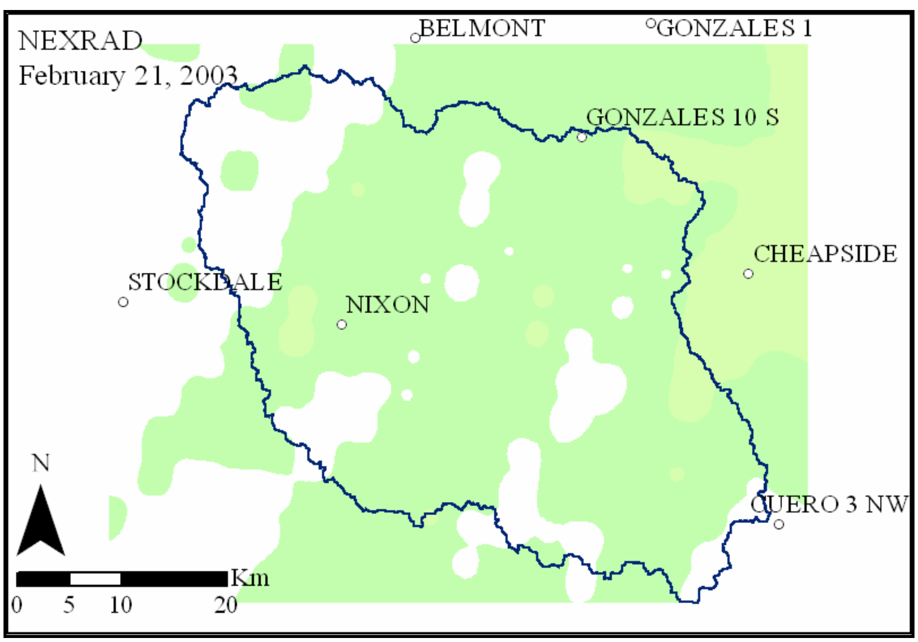


Figure B.4: NEXRAD February 21, 2003

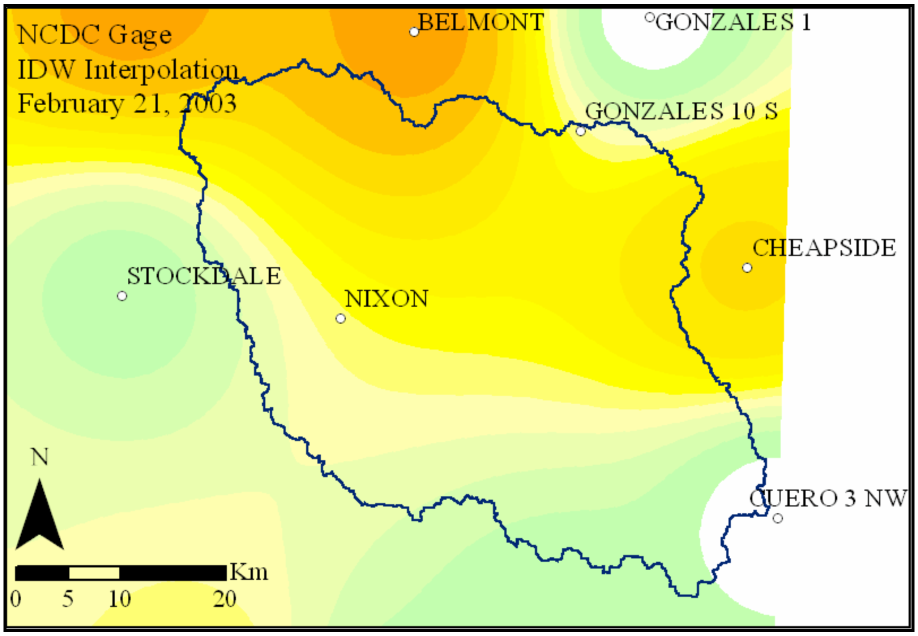


Figure B.5: NCDC Gage IDW Interpolation February 21, 2003

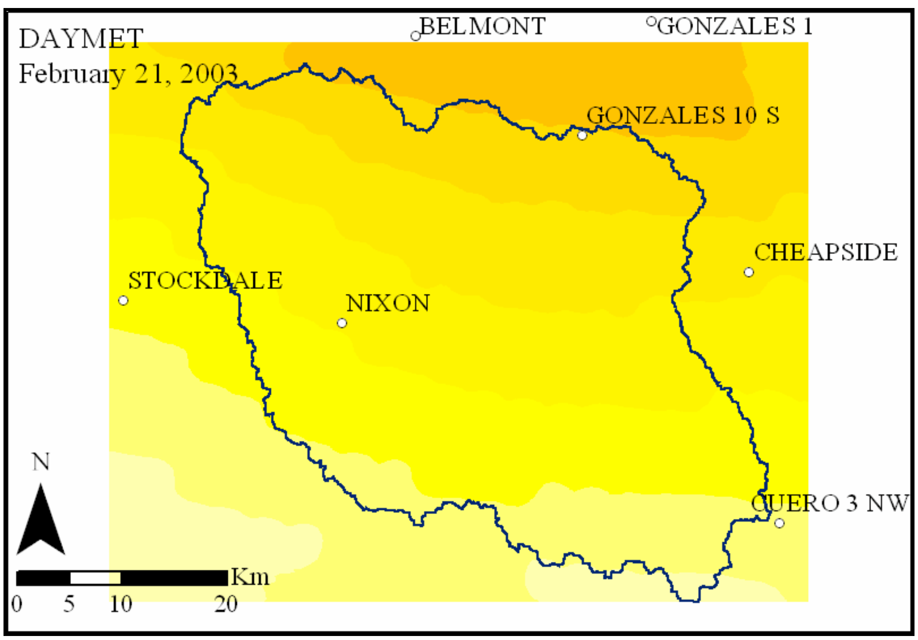


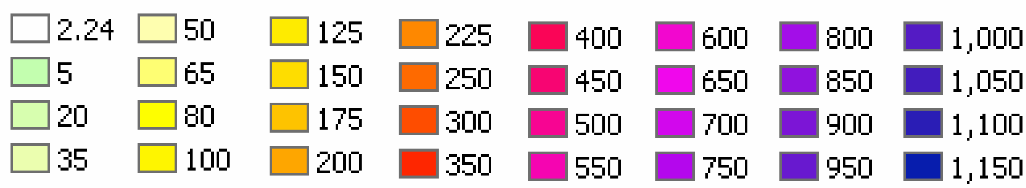
Figure B.6: DAYMET Gage Interpolation February 21, 2003

FEBRUARY 21, 2003 STORM

There was such a large discrepancy between NEXRAD and NCDC gage interpolation that the entire storm was interpolated and checked.

NCDC Missing Stations: Gonzales 10 SW and Nixon

USGS Gage Flow	Day Before:	219 cfs	Day After:	2460 cfs
NEXRAD	Minimum:	0.24 in.	Maximum:	2.18 in.
NCDC	Minimum:	0 in.	Maximum:	2.80 in.
Convective Cells:	Number:	4	Size:	5 Km



Scale (hundredth inch)

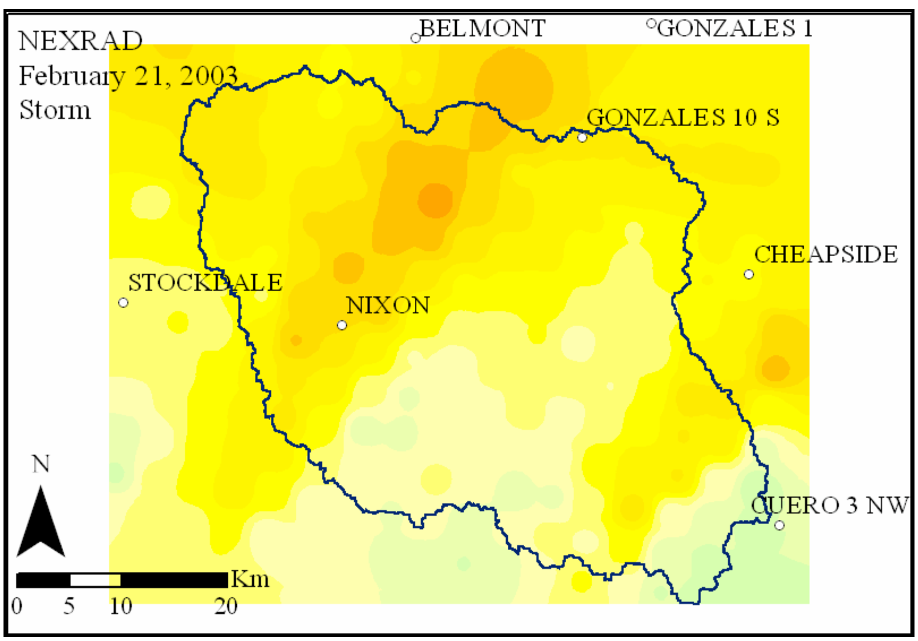


Figure B.7: NEXRAD 2/19/2003 thru 2/22/2003

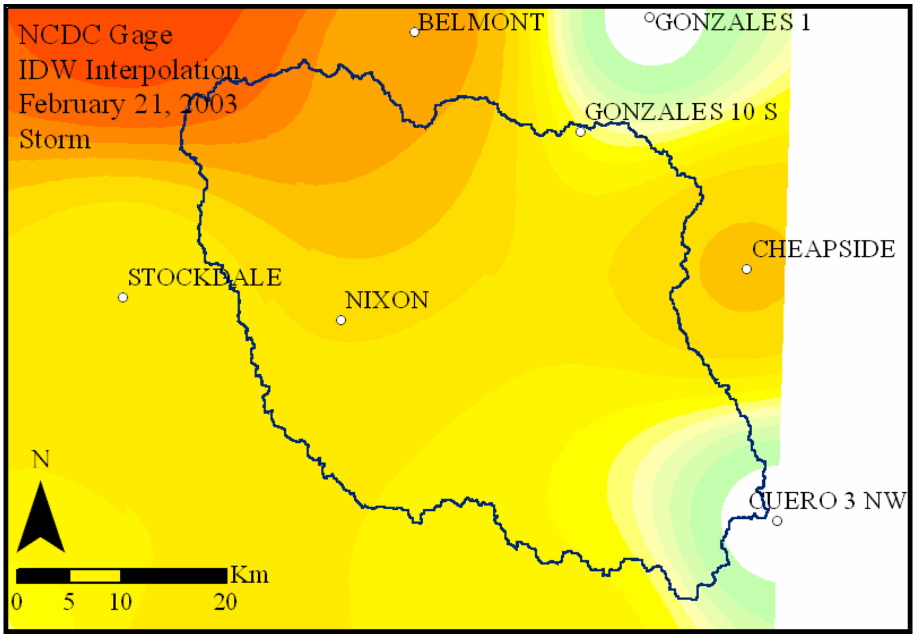


Figure B.8: NCDC Gage IDW Interpolation 2/19/2003 thru 2/22/2003

Given the very significant increase in flow at the gauge from 219 cfs to 2460 cfs from February 20, 2003 to February 23, 2003 it is reasonable to guess that NEXRAD underestimated this storm rather than NCDC gauges overestimating it.

The entire storm is not nearly as undervalued as the one day of rain in February that was initially evaluated. NEXRAD still underestimates the storm by 35.8%; see Table B.1 below, but the range, mean, and standard deviation are much closer together.

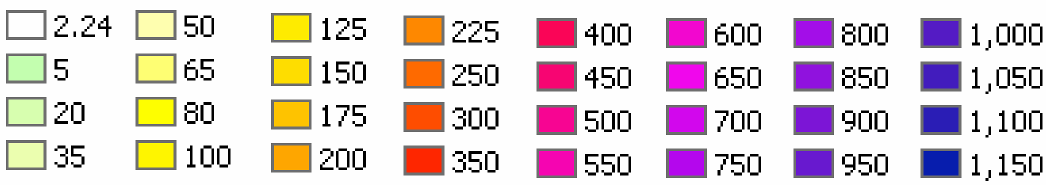
Table B.1: Spatial Analysis of Precipitation Methods over Sandies & Elm Watershed

Date	**Type**	**Total (in)**	**Min (in)**	**Max (in)**	**Mean (in)**	**Std. Dev. (in)**
February 21, 2003 Storm	NCDC	256,309.00	0.00	2.80	1.39	0.49
	NEXRAD	188,752.00	0.24	2.18	1.02	0.40
	Difference	**-35.8%**	**0.24**	**-0.62**	**-0.37**	**-0.09**

MARCH 14, 2000

NCDC Missing Stations: Kingsbury and New Braunfels Municipal AP

USGS Gage Flow	Day Before:	22 cfs	Day After:	290 cfs
NEXRAD	Minimum:	1.07 in.	Maximum:	3.58 in.
NCDC	Minimum:	0 in.	Maximum:	1.86 in.
Convective Cells:	Number:	1	Size:	5 Km.



Scale (hundredth inch)

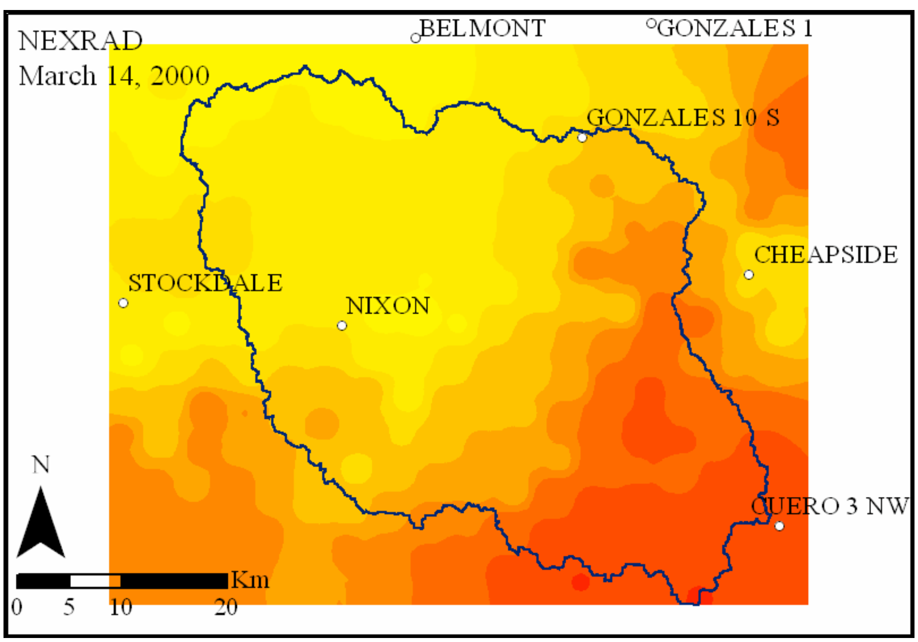


Figure B.9: NEXRAD March 14, 2000

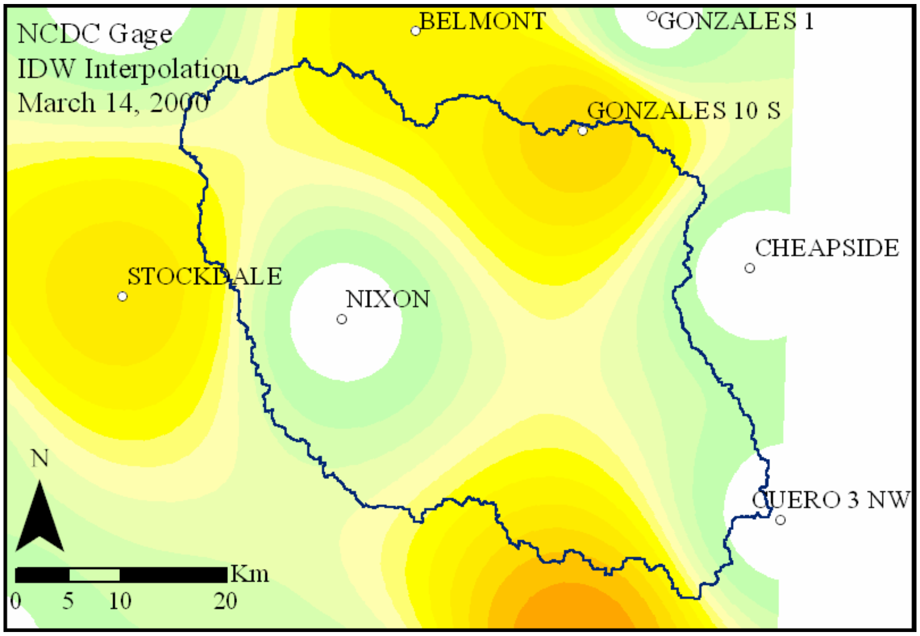


Figure B.10: NCDC Gage IDW Interpolation March 14, 2000

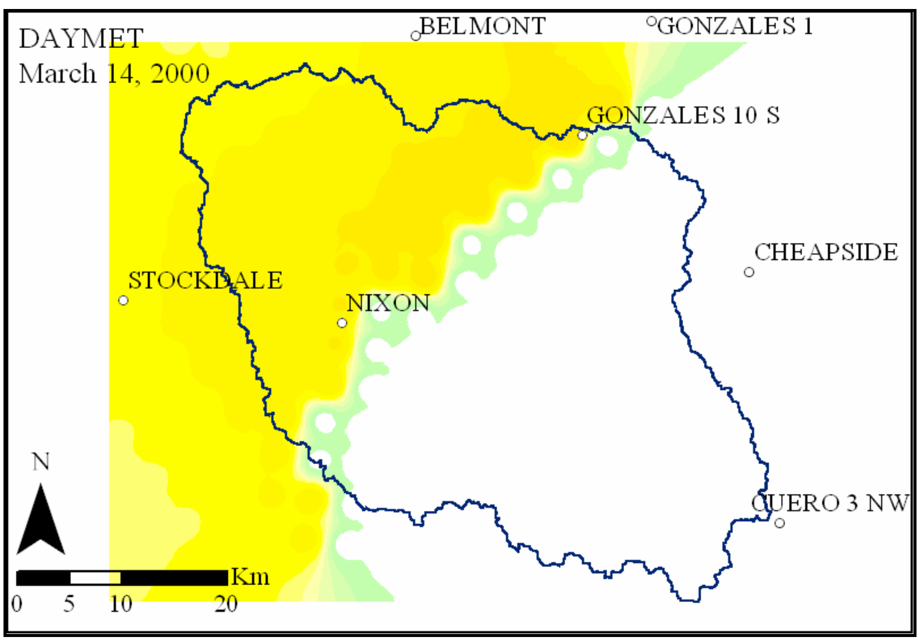


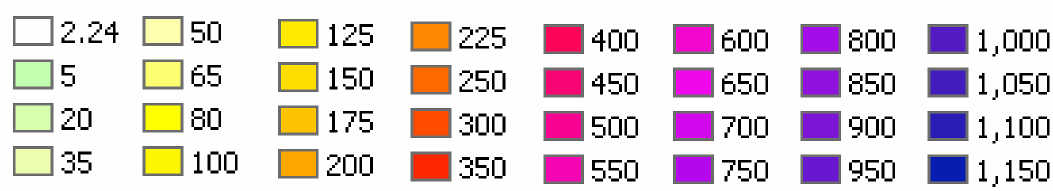
Figure B.11: DAYMET Gage Interpolation March 14, 2000

MARCH 14, 2000 STORM

There was such a large discrepancy between NEXRAD and NCDC gage interpolation that the entire storm was interpolated and checked.

NCDC Missing Stations: Kingsbury and New Braunfels Municipal AP

USGS Gage Flow	Day Before:	22 cfs	Day After:	218 cfs
NEXRAD	Minimum:	1.07 in.	Maximum:	3.58 in.
NCDC	Minimum:	1.00 in.	Maximum:	2.11 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

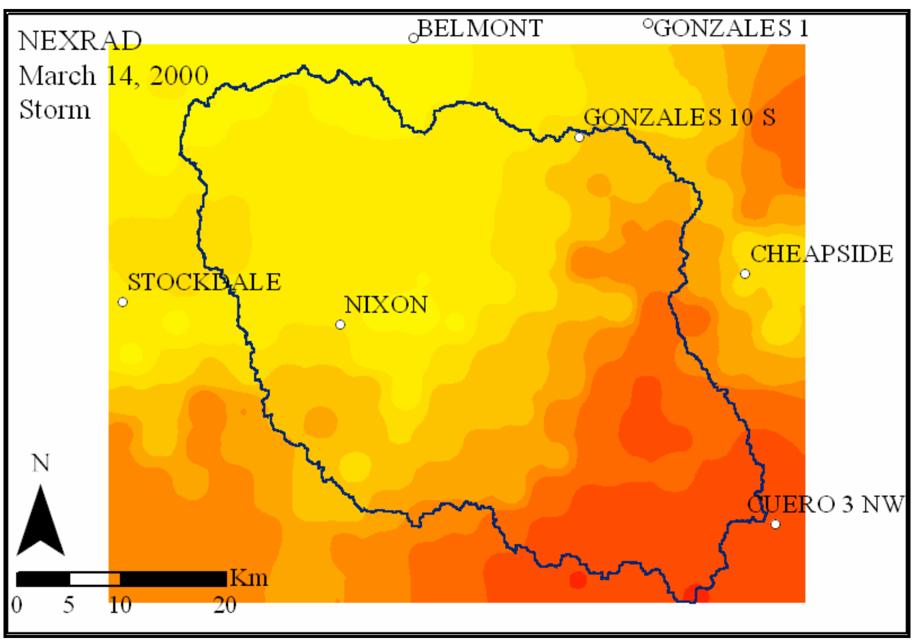


Figure B.12: NEXRAD 3/14/2000 thru 3/15/2000

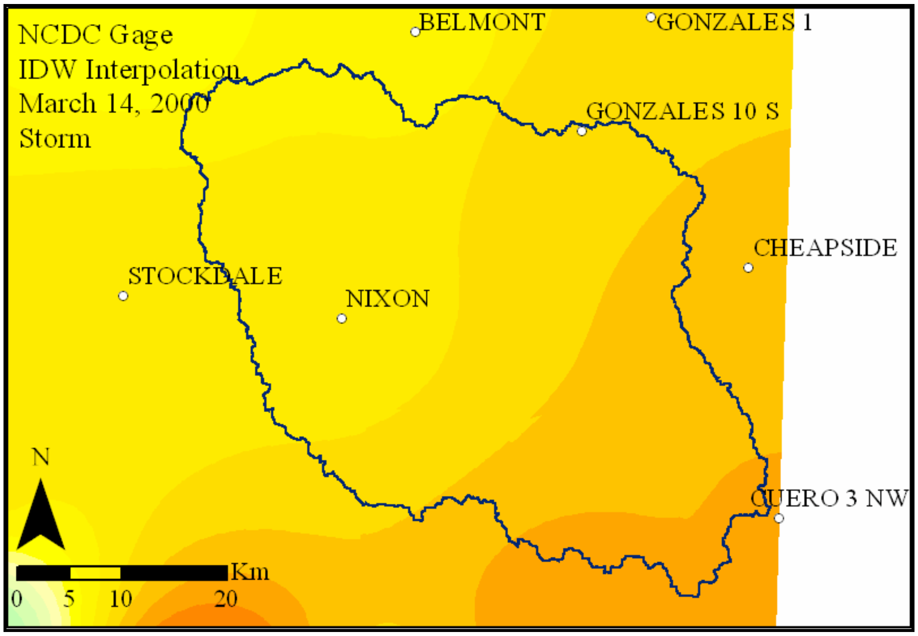


Figure B.13: NCDC Gage IDW Interpolation 3/14/2000 thru 3/15/2000

NEXRAD indicates that the rain from this storm fell between 6:00 pm on March 14, 2000 and 6 am on March 15, 2000. Therefore the storm should be encompassed by one day of NCDC daily gage data, if the measurements were taken at 7 am as the output suggests. Instead the data is spread over three days, March 14, 15, and 16.

The storm totals compare very well, as seen in Table B.2 below, though the pattern of the rainfall is incongruent.

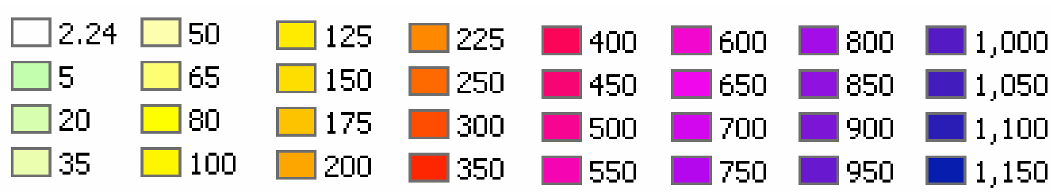
Table B.2: Spatial Analysis of Precipitation Methods over Sandies & Elm Watershed

Date	Type	Total (in)	Min (in)	Max (in)	Mean (in)	Std. Dev. (in)
March 14, 2000 Storm	NCDC	296079.00	1.00	2.11	1.61	0.24
	NEXRAD	357,625.00	1.07	3.58	1.94	0.63
	Difference	**17.2%**	**0.07**	**1.47**	**0.33**	**0.39**

APRIL 8, 2002

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	9.9 cfs	Day After:	784 cfs
NEXRAD	Minimum:	0.47 in.	Maximum:	5.56 in.
NCDC	Minimum:	1.10 in.	Maximum:	5.08 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

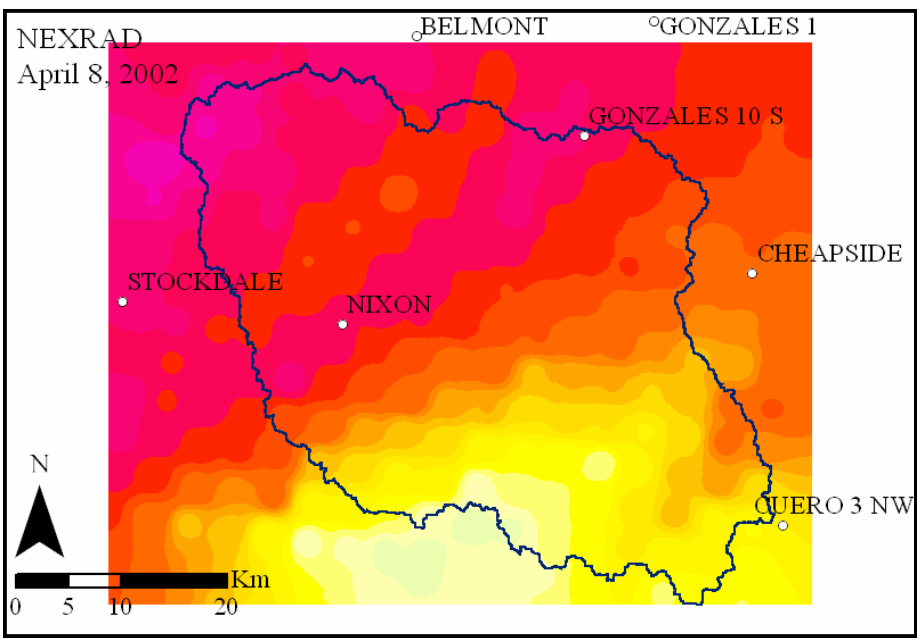


Figure B.14: NEXRAD April 8, 2002

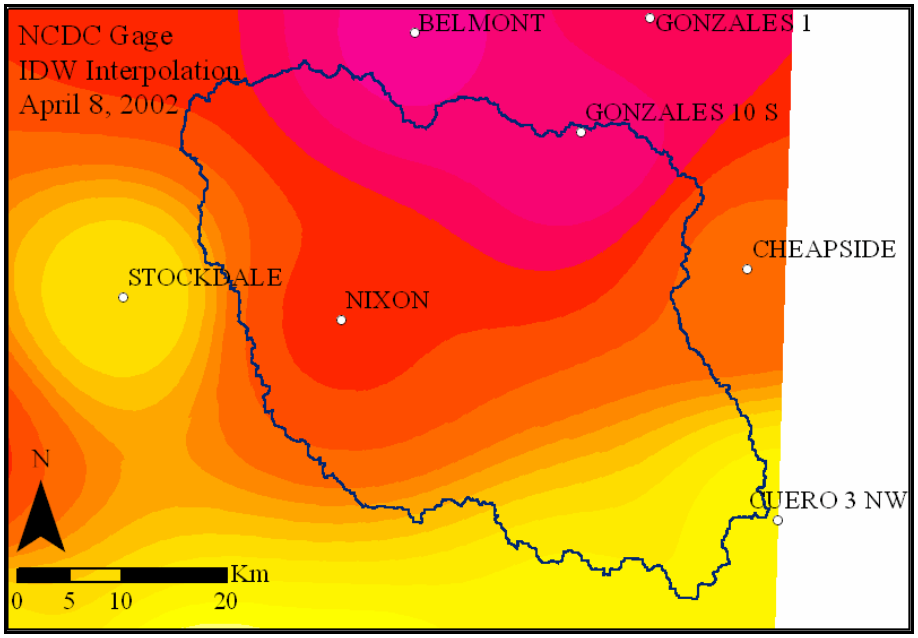


Figure B.15: NCDC Gage IDW Interpolation April 8, 2002

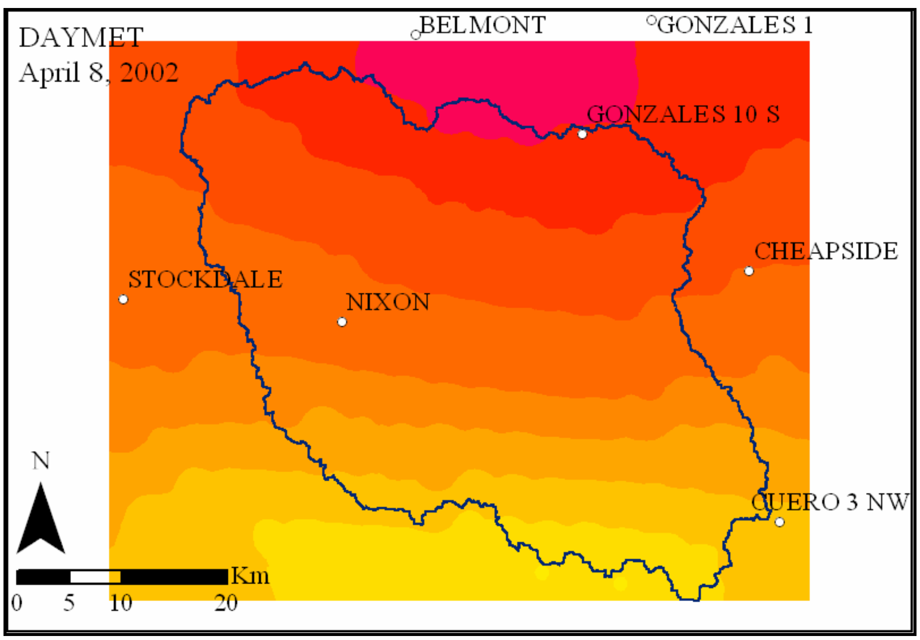
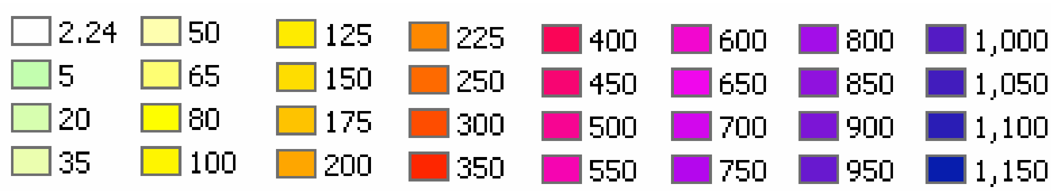


Figure B.15: DAYMET Gage Interpolation April 8, 2002

MAY 20, 2000

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	11 cfs	Day After:	209 cfs
NEXRAD	Minimum:	0.17 in.	Maximum:	3.26 in.
NCDC	Minimum:	0 in.	Maximum:	4.20 in.
Convective Cells:	Number:	3	Size:	5 km.



Scale (hundredth inch)

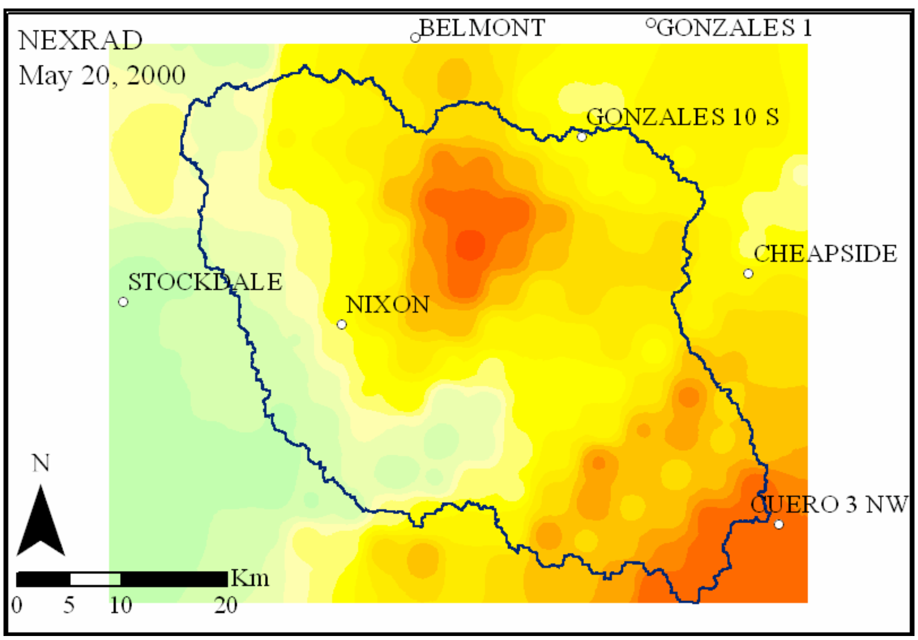


Figure B.16: NEXRAD May 20, 2000

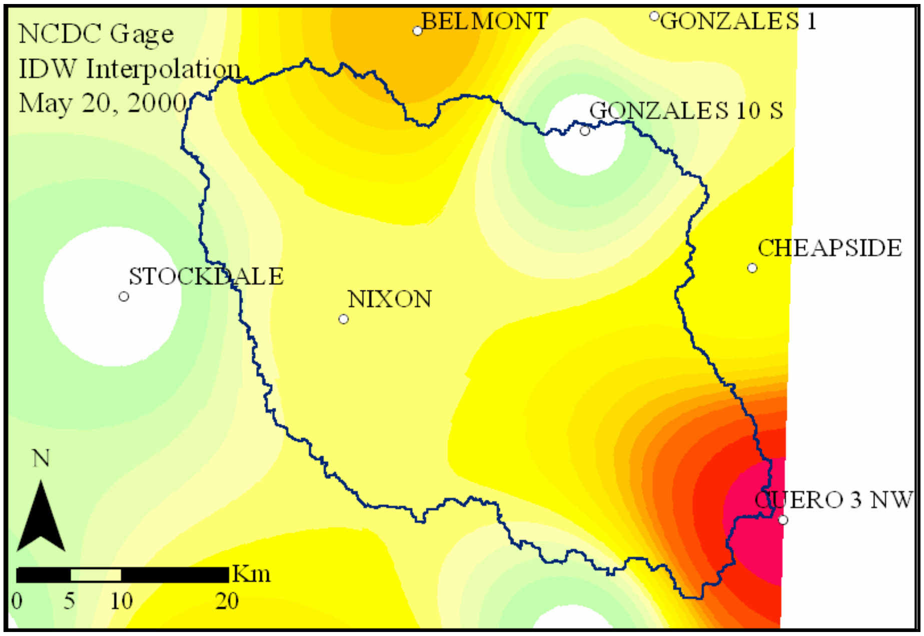


Figure B.17: NCDC Gage IDW Interpolation May 20, 2000

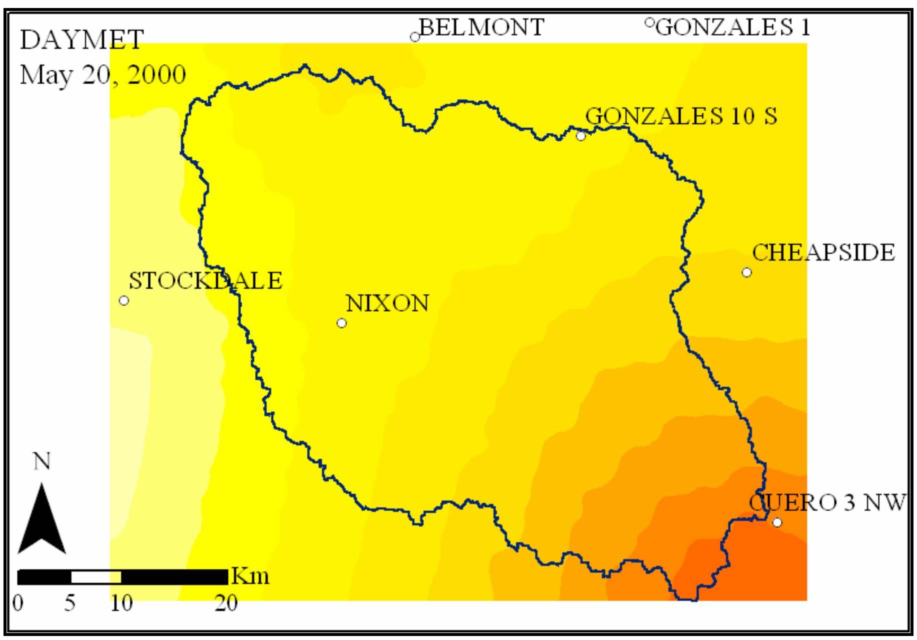
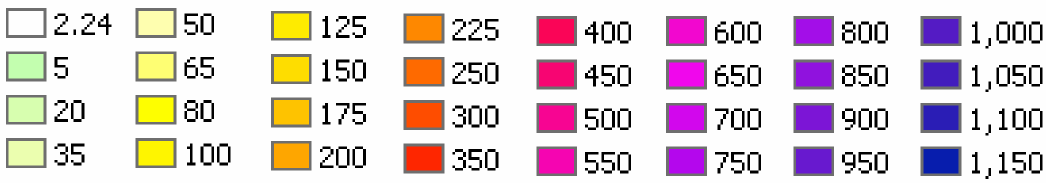


Figure B.18: DAYMET Gage Interpolation May 20, 2000

JUNE 30, 2002

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	8.9 cfs	Day After:	292 cfs
NEXRAD	Minimum:	1.0 in.	Maximum:	3.51 in.
NCDC	Minimum:	0.8 in.	Maximum:	3.74 in.
Convective Cells:	Number:	1	Size:	15 km.



Scale (hundredth inch)

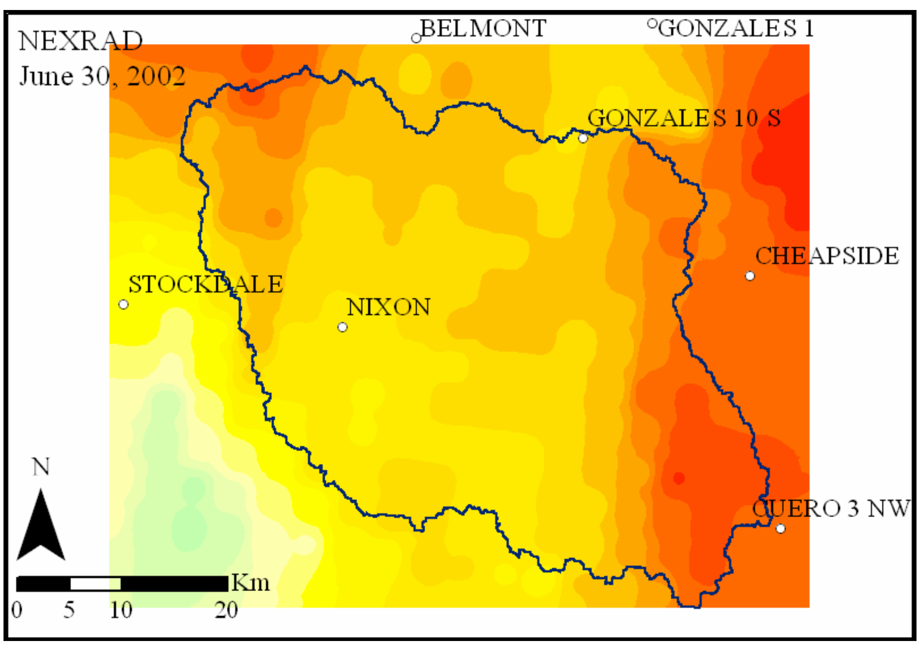


Figure B.19: NEXRAD June 30, 2002

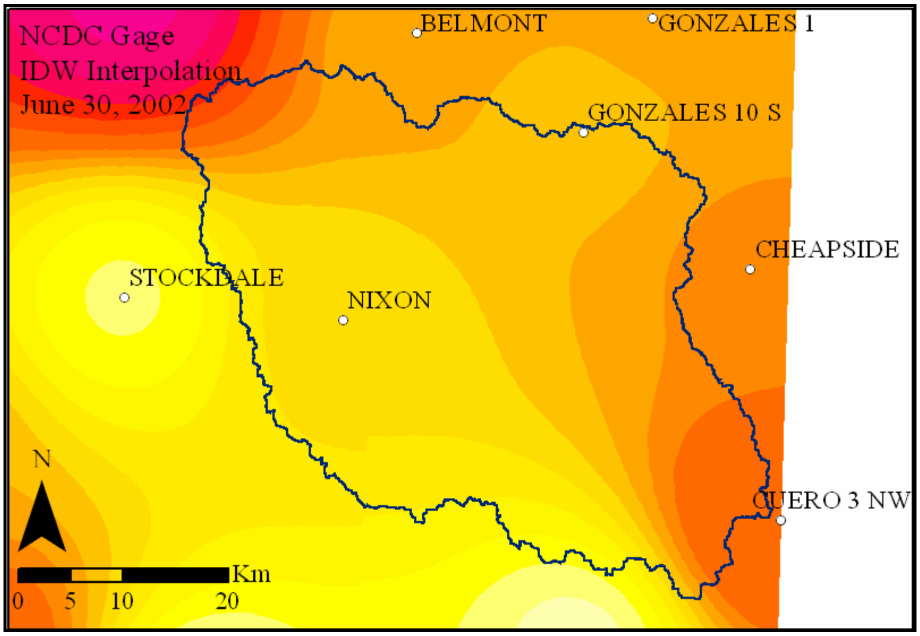


Figure B.20: NCDC Gage IDW Interpolation June 30, 2002

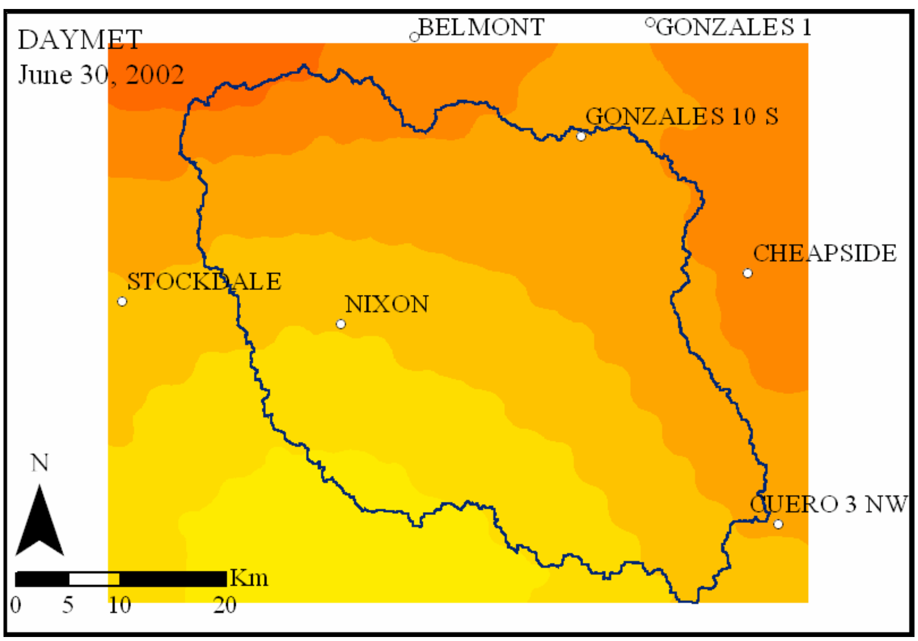
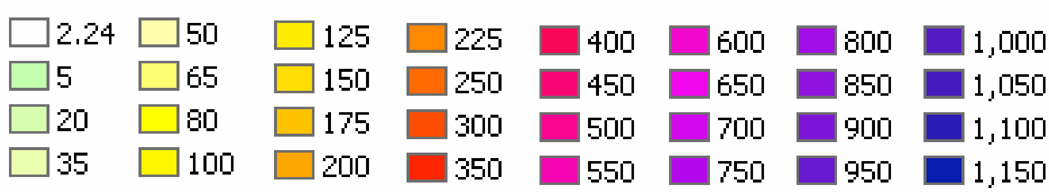


Figure B.21: DAYMET Gage Interpolation June 30, 2002

JULY 15, 2002

NCDC Missing Stations: New Braunfels Municipal AP

USGS Gage Flow	Day Before:	85 cfs	Day After:	1090 cfs
NEXRAD	Minimum:	1.67 in.	Maximum:	4.71 in.
NCDC	Minimum:	0.71 in.	Maximum:	1.90 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

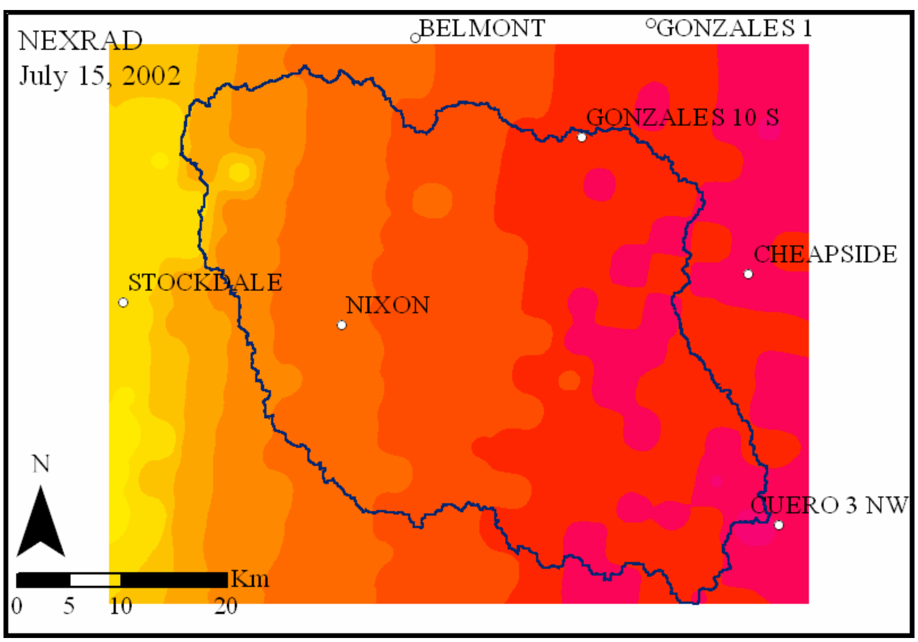


Figure B.22: NEXRAD July 15, 2002

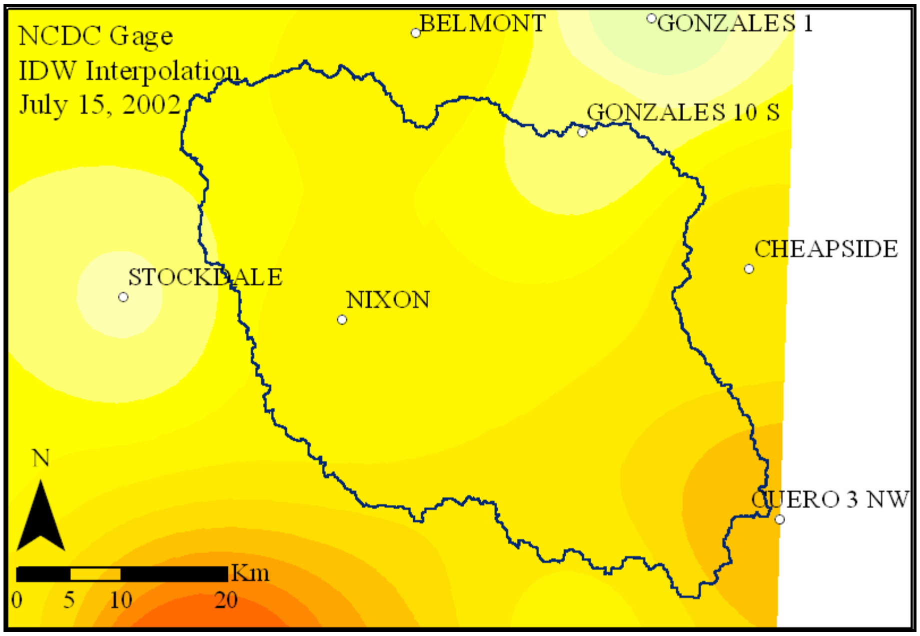


Figure B.23: NCDC Gage IDW Interpolation July 15, 2002

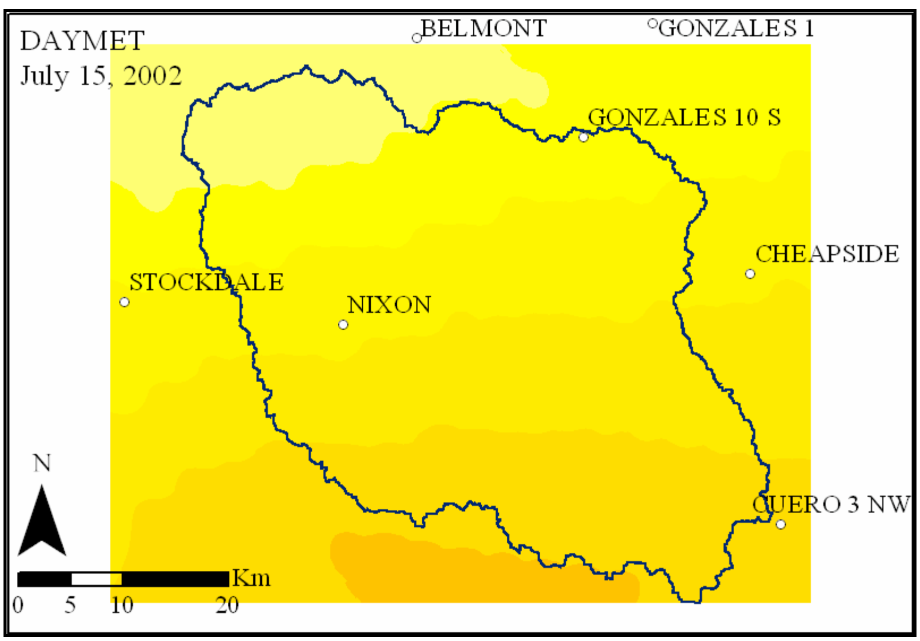
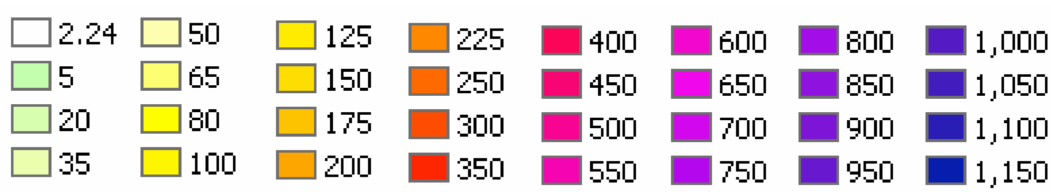


Figure B.24: DAYMET Gage Interpolation July 15, 2002

AUGUST 31, 2001

NCDC Missing Stations: Falls City 4WNW, Karnes City, and New Braunfels MAP

USGS Gage Flow	Day Before:	174 cfs	Day After:	25,900 cfs
NEXRAD	Minimum:	0.77 in.	Maximum:	9.17 in.
NCDC	Minimum:	0.32 in.	Maximum:	8.30 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

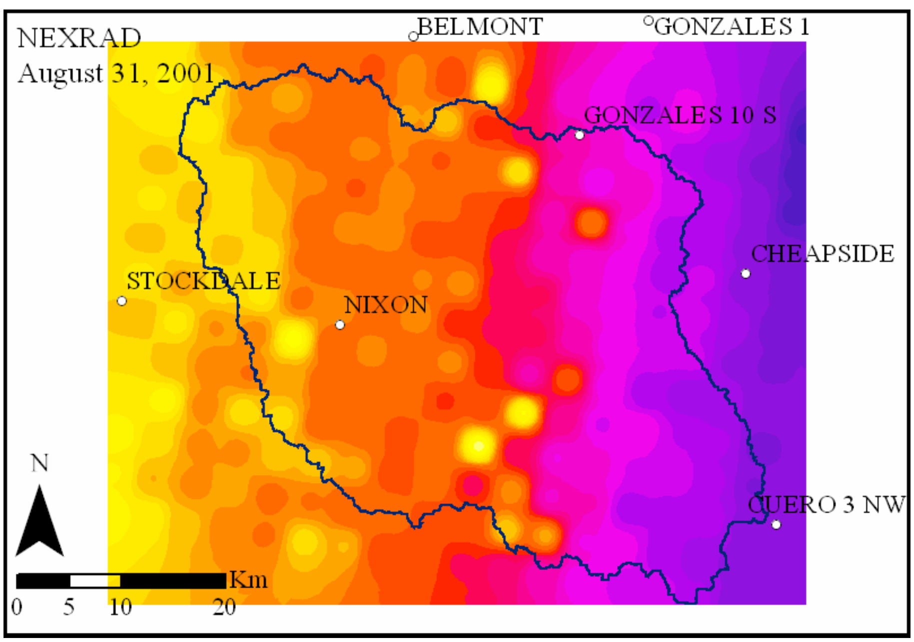


Figure B.25: NEXRAD August 31, 2001

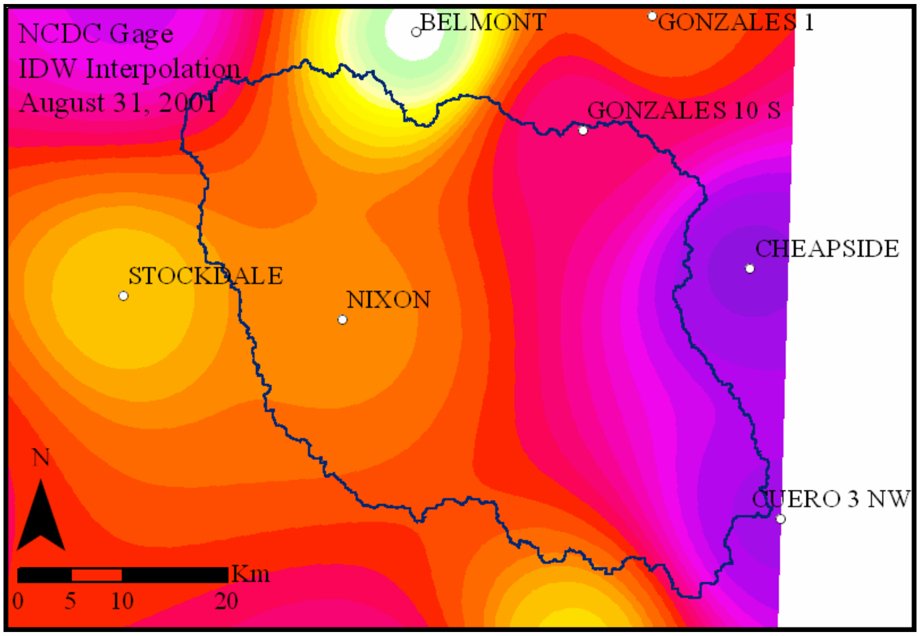


Figure B.26: NCDC Gage IDW Interpolation August 31, 2001

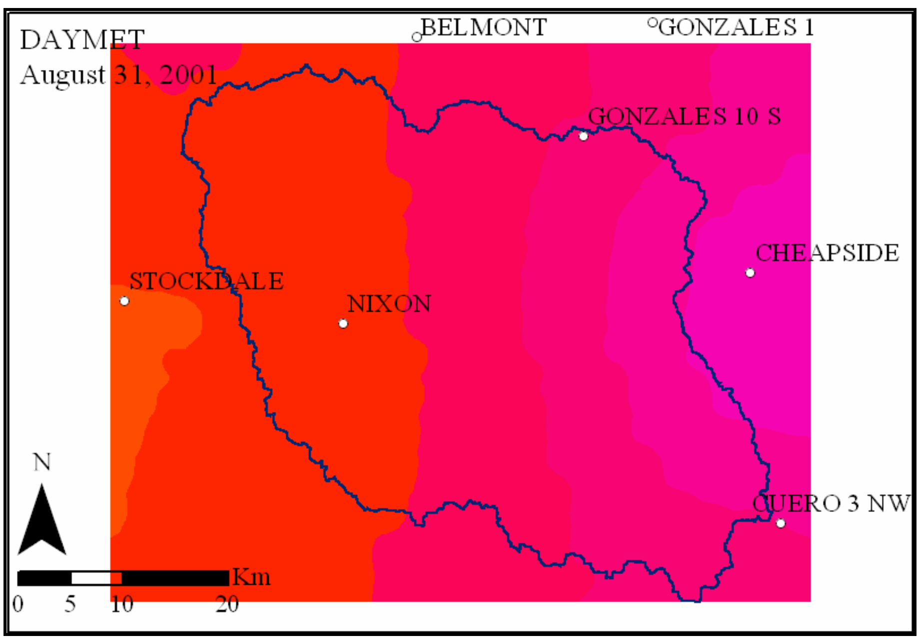
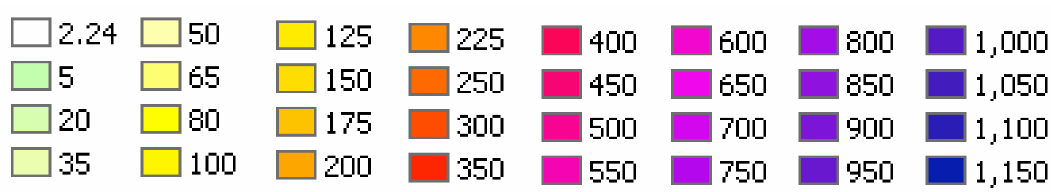


Figure B.27: DAYMET Gage Interpolation August 31, 2001

SEPTEMBER 7, 2002

NCDC Missing Stations: Cuero 3 NW

USGS Gage Flow	Day Before:	2.2 cfs	Day After:	25 cfs
NEXRAD	Minimum:	0.03 in.	Maximum:	4.23 in.
NCDC	Minimum:	1.27 in.	Maximum:	4.98 in.
Convective Cells:	Number:	1	Size:	10 km.



Scale (hundredth inch)

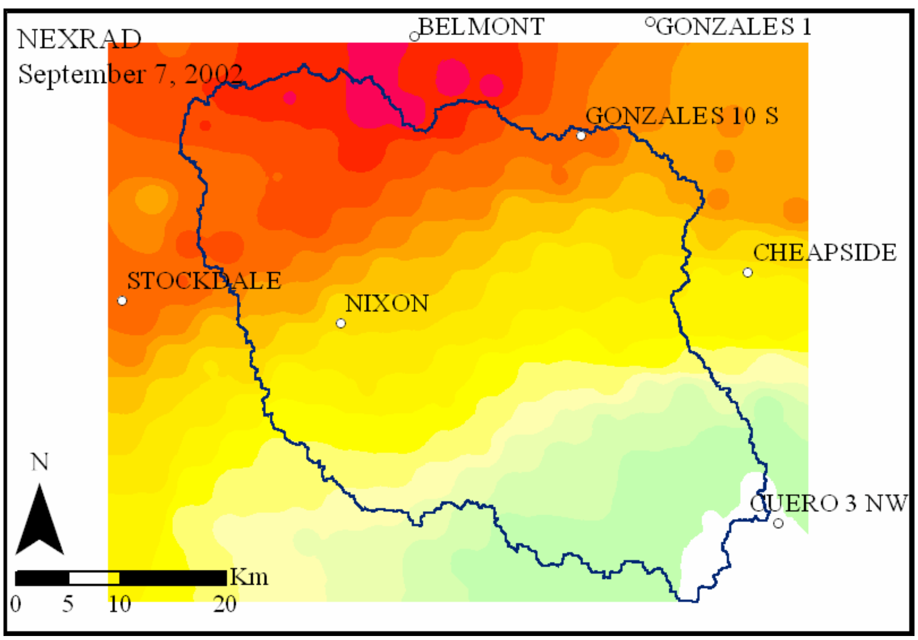


Figure B.28: NEXRAD September 7, 2002

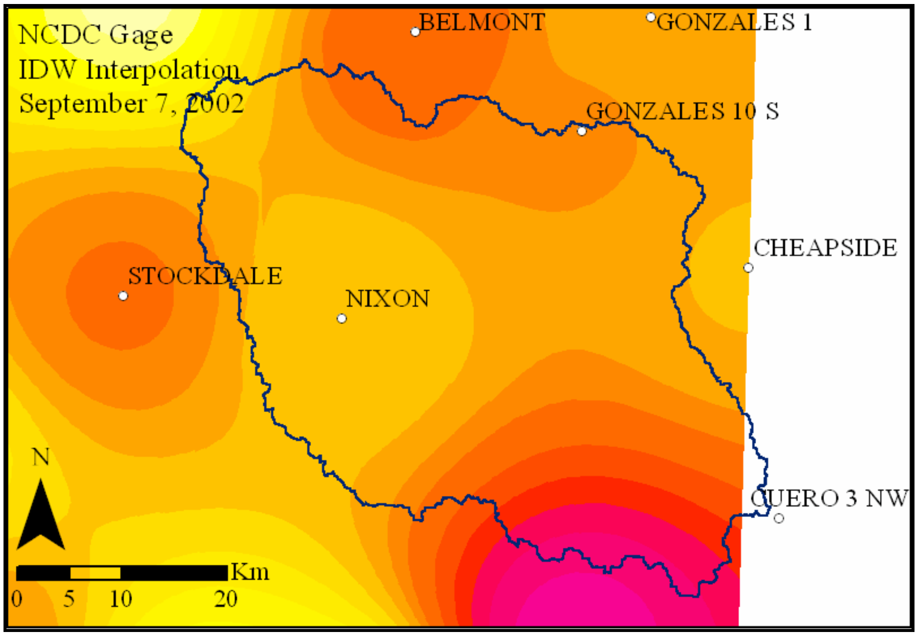


Figure B.29: NCDC Gage IDW Interpolation September 7, 2002

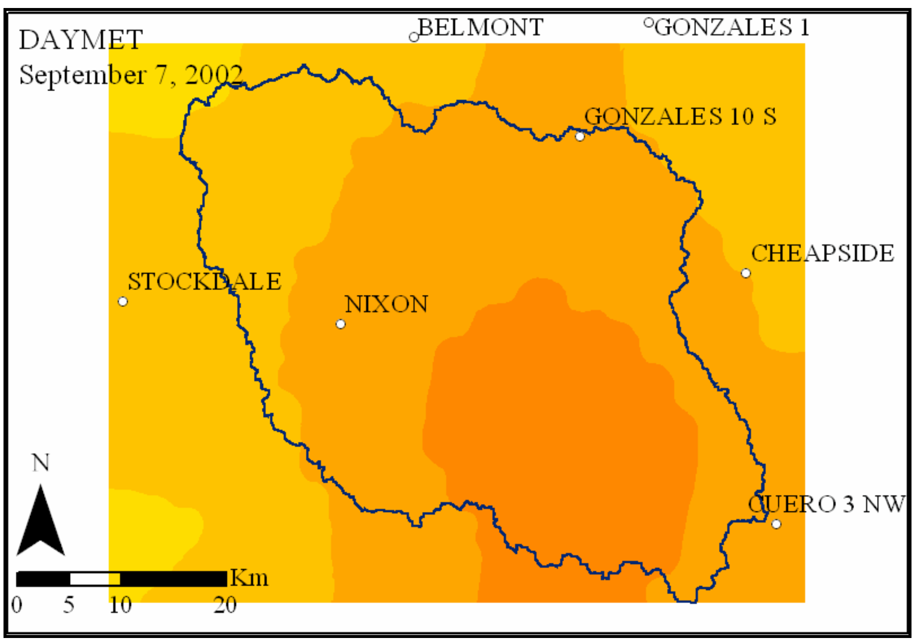
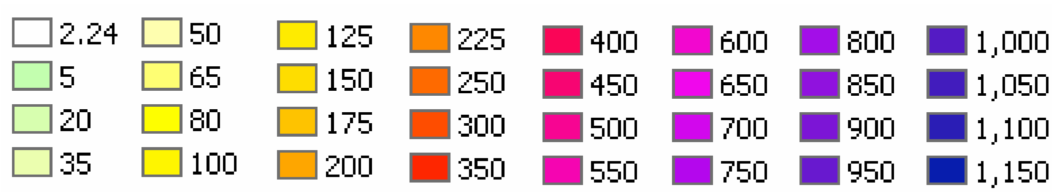


Figure B.30: DAYMET Gage Interpolation September 7, 2002

OCTOBER 9, 2002

NCDC Missing Stations: Nixon

USGS Gage Flow	Day Before:	1.1 cfs	Day After:	4.0 cfs
NEXRAD	Minimum:	0.63 in.	Maximum:	4.49 in.
NCDC	Minimum:	0.22 in.	Maximum:	6.29 in.
Convective Cells:	Number:	0	Size:	NA



Scale (hundredth inch)

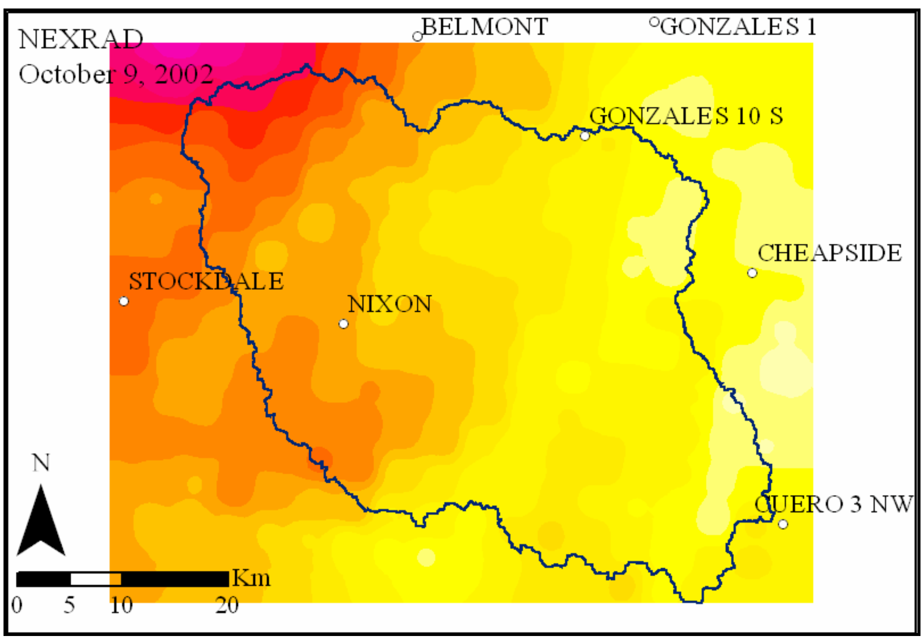
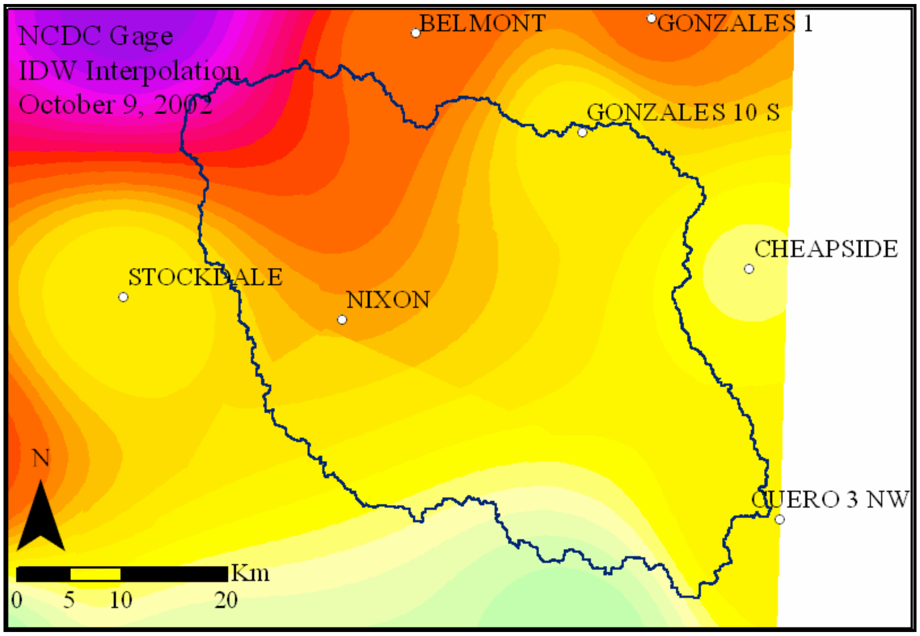


Figure B.31: NEXRAD October 9, 2002



FigureB.32: NCDC Gage IDW Interpolation October 9, 2002

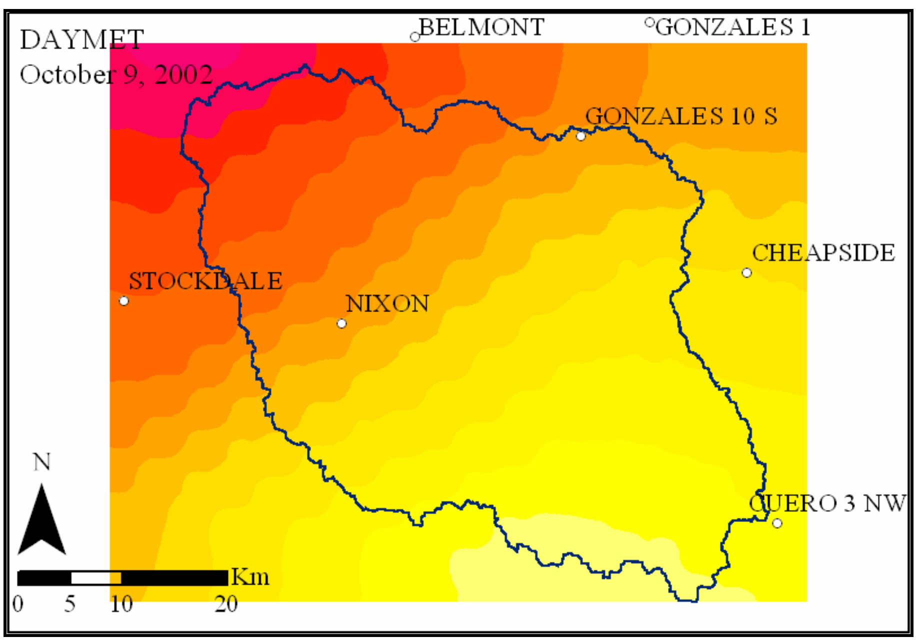
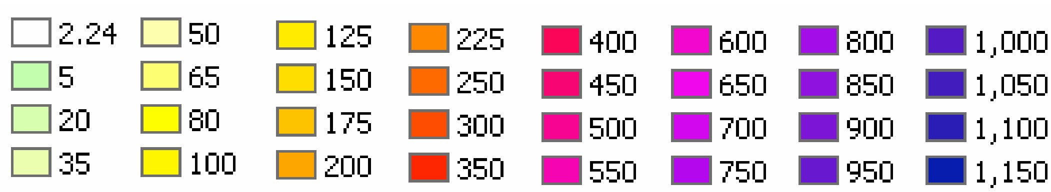


Figure B.33: DAYMET Gage Interpolation October 9, 2002

NOVEMBER 17, 2003

NCDC Missing Stations: Nixon

USGS Gage Flow	Day Before:	6.8 cfs	Day After:	8.5 cfs
NEXRAD	Minimum:	0.13 in.	Maximum:	4.0 in.
NCDC	Minimum:	0.03 in.	Maximum:	5.3 in.
Convective Cells:	Number:	1	Size:	10 km.



Scale (hundredth inch)

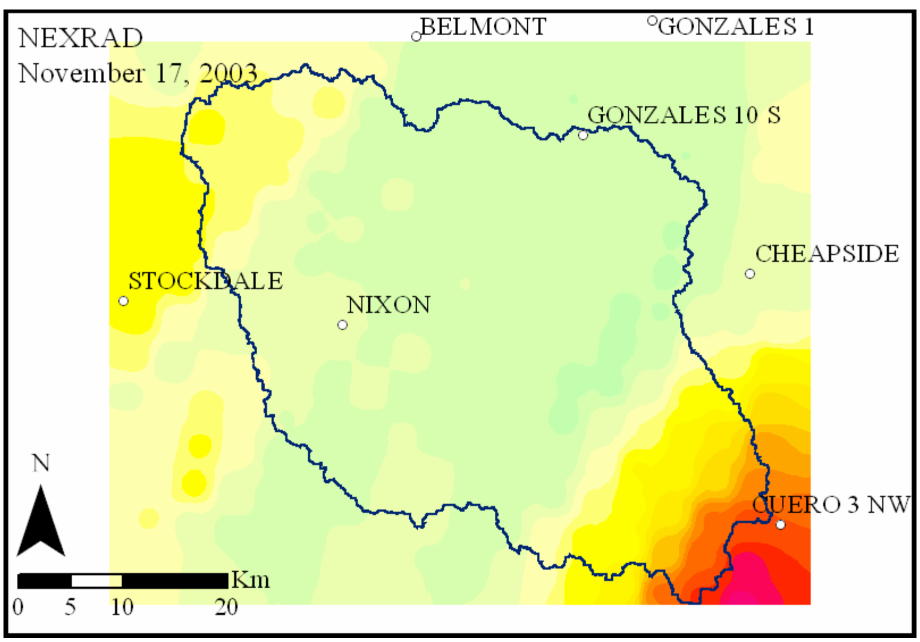


Figure B.34: NEXRAD November 17, 2003

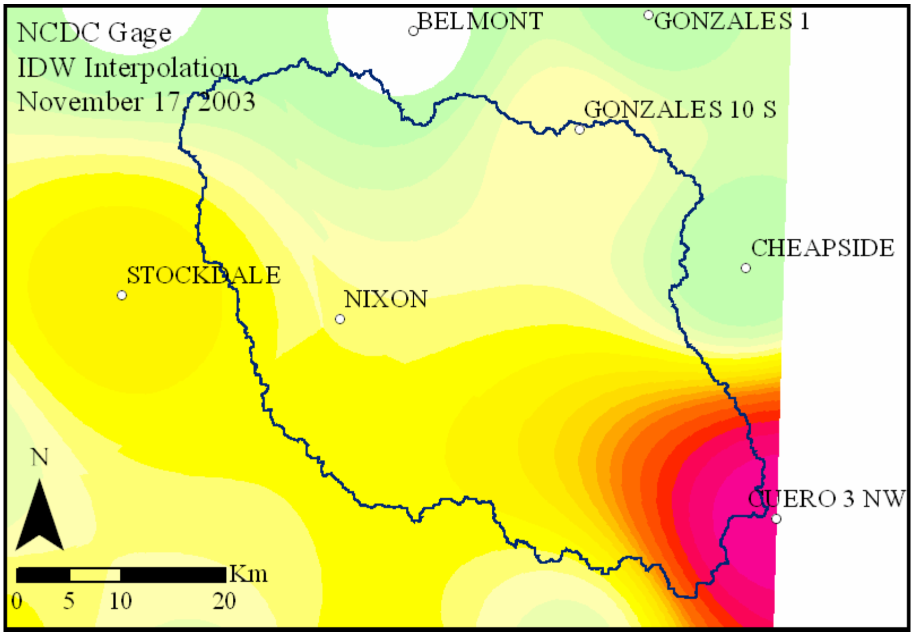


Figure B.35: NCDC Gage IDW Interpolation November 17, 2003

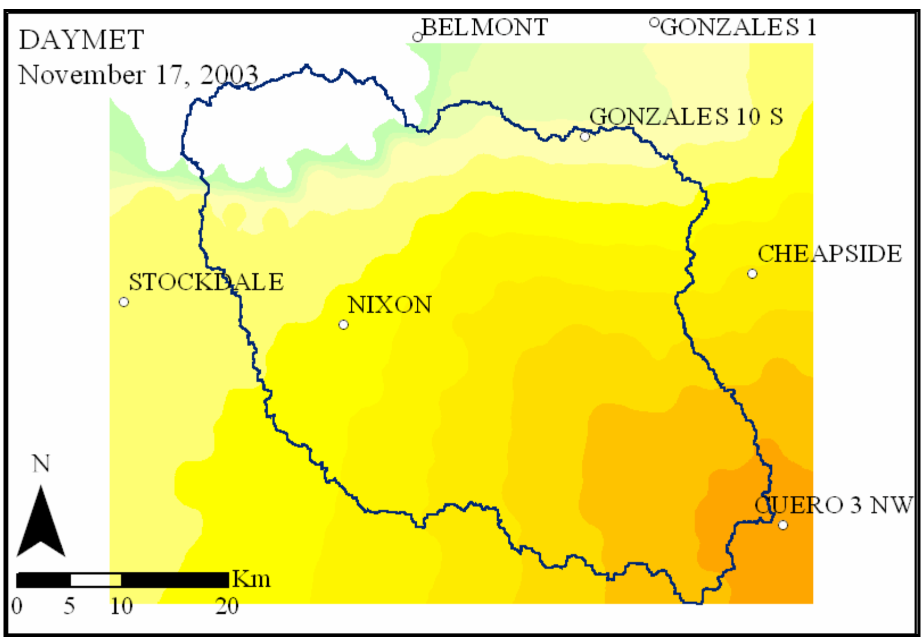


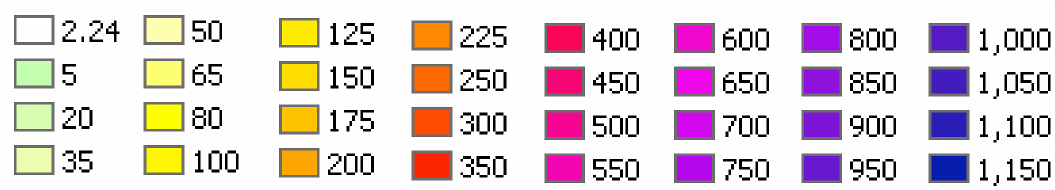
Figure B.36: DAYMET Gage Interpolation November 17, 2003

DECEMBER 4, 2002

NCDC Missing Stations: Nixon

USGS Gage Flow	Day Before:	15 cfs	Day After:	32 cfs
NEXRAD	Minimum:	0.85 in.	Maximum:	2.29 in.
NCDC	Minimum:	0 in.	Maximum:	2.45 in.

Convective Cells: Number: 2 Size: 5 km. Scale



(hundredth inch)

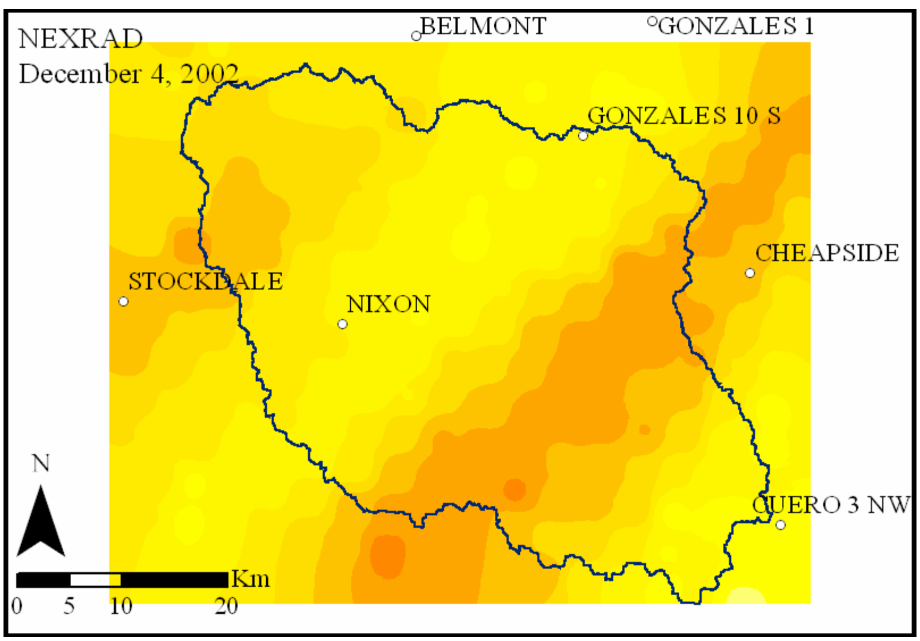


Figure B.37: NEXRAD December 4, 2002

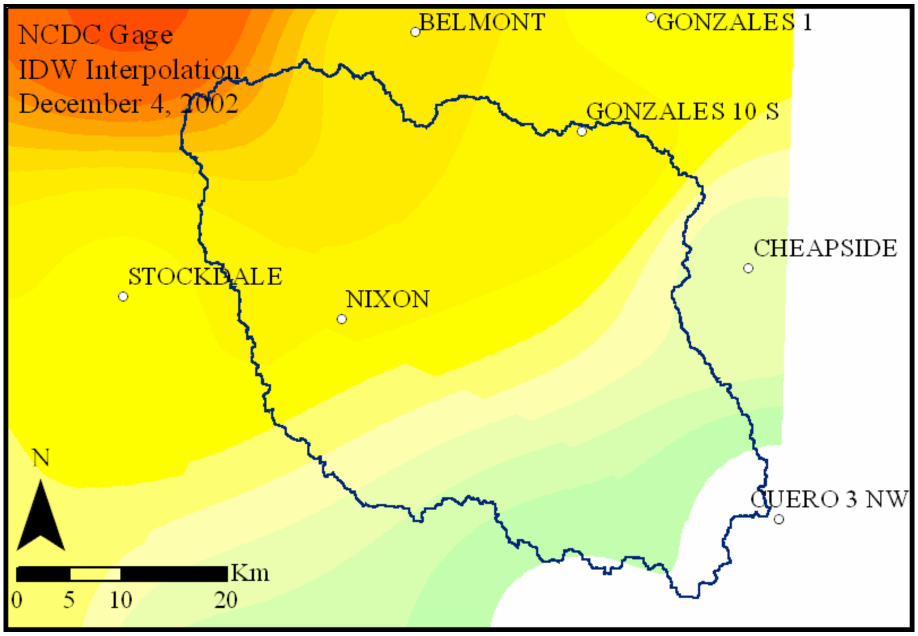


Figure B.38: NCDC Gage IDW Interpolation December 4, 2002

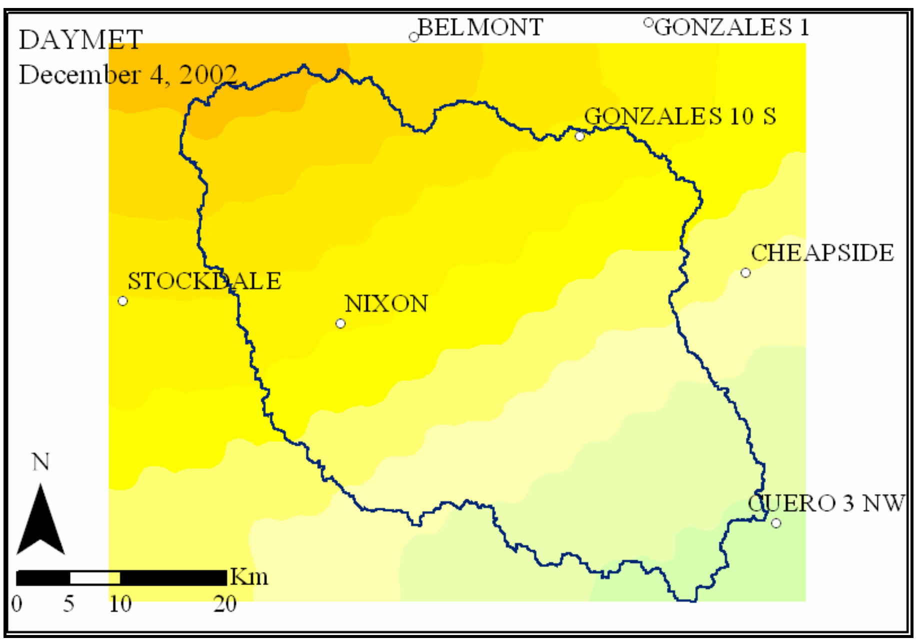


Figure B.39: DAYMET Gage Interpolation December 4, 2002

Appendix C

Upper Sandies and Elm															
No.	HydroCode	Length	Drain Area (Mi^2)	Long. Slope	Main Channel				Lower Floodplain			Upper Floodplain		
					Flow	Bottom Width	Depth	Top Width	Flow	Depth	Top Width	Flow	Depth	Top Width
1	Little Elm Creek	6,937.78	5.70	0.0033	4.56	0.05	1.23	6.20	35.21	1.42	26.07	220.17	0.92	488.67
2	Clear Fork Creek	18,331.27	40.48	0.0033	32.37	0.50	2.48	12.92	249.97	2.96	54.33	1,563.22	1.91	1,018.43
3	Tally Branch	8,337.55	11.12	0.0040	8.89	0.15	1.51	7.70	68.66	1.76	32.40	429.38	1.14	607.24
4	Clear Fork Creek	5,122.41	58.56	0.0012	46.82	0.70	3.47	18.05	361.58	4.13	75.90	2,261.21	2.67	1,422.58
5	Nose Creek	8,303.13	8.80	0.0041	7.04	0.10	1.38	7.01	54.33	1.61	29.49	339.75	1.04	552.67
6	Murray Branch	6,624.53	5.60	0.0053	4.48	0.05	1.12	5.64	34.57	1.29	23.73	216.21	0.84	444.74
7	Murray Branch	1,732.36	15.75	0.0012	12.59	0.20	2.17	11.05	97.23	2.53	46.51	608.07	1.64	871.68
8	Clear Fork Creek	1,627.51	74.86	0.0018	59.86	0.90	3.46	18.18	462.27	4.16	76.44	2,890.86	2.69	1,432.72
9	Red Branch	7,234.84	5.94	0.0051	4.75	0.05	1.15	5.80	36.70	1.33	24.41	229.54	0.86	457.62
10	Clear Fork Creek	12,642.99	100.29	0.0011	80.19	1.20	4.23	22.33	619.29	5.11	93.85	3,872.87	3.30	1,759.08
11	Salt Branch	7,465.12	8.69	0.0043	6.95	0.10	1.36	6.92	53.66	1.58	29.10	335.54	1.02	545.39
12	Cordell Creek	5,563.44	3.91	0.0086	3.13	0.05	0.89	4.50	24.15	1.03	18.92	151.01	0.67	354.59
13	Sandies Creek	5,078.17	8.33	0.0096	6.66	0.10	1.15	5.85	51.43	1.34	24.60	321.64	0.87	461.05
14	Sandies Creek	7,362.58	33.68	0.0042	26.93	0.40	2.23	11.54	207.99	2.64	48.53	1,300.69	1.71	909.55
15	Tidwell Creek	7,052.61	7.78	0.0104	6.22	0.10	1.10	5.62	48.03	1.29	23.66	300.34	0.83	443.48
16	Sandies Creek	10,970.50	74.27	0.0018	59.39	0.90	3.45	18.17	458.61	4.16	76.37	2,868.02	2.69	1,431.42
17	Sandies Creek	8,009.60	91.73	0.0012	73.35	1.10	4.00	21.11	566.44	4.83	88.74	3,542.34	3.12	1,663.36
18	Talley Branch	9,465.83	8.17	0.0049	6.53	0.10	1.30	6.60	50.44	1.51	27.77	315.41	0.98	520.49
19	East Fork O'Neal Creek	7,374.45	6.68	0.0046	5.34	0.10	1.22	6.18	41.22	1.42	26.00	257.79	0.92	487.36
20	O'Neal Creek	12,593.83	23.15	0.0056	18.51	0.25	1.85	9.49	142.97	2.17	39.92	894.11	1.41	748.20
21	O'Neal Creek	1,894.32	32.47	0.0026	25.96	0.40	2.40	12.42	200.49	2.84	52.24	1,253.80	1.84	979.21
22	Baker Branch	7,836.60	6.17	0.0040	4.93	0.05	1.22	6.17	38.07	1.41	25.97	238.09	0.91	486.82
23	O'Neal Creek	2,562.95	41.80	0.0012	33.42	0.50	3.08	15.90	258.10	3.64	66.89	1,614.07	2.35	1,253.79
24	O'Neal Creek	6,820.52	58.17	0.0013	46.51	0.70	3.38	17.60	359.17	4.03	74.03	2,246.14	2.61	1,387.66
25	Sandies Creek	1,175.87	152.24	0.0009	121.73	1.80	5.13	27.45	940.06	6.28	115.32	5,878.84	4.06	2,161.48
26	Sandies Creek	654.17	152.81	0.0015	122.19	1.80	4.57	24.64	943.59	5.63	103.46	5,900.91	3.64	1,939.15
27	Yow Branch	10,363.24	11.55	0.0041	9.23	0.15	1.53	7.78	71.30	1.78	32.71	445.90	1.15	613.17

Upper Sandies and Elm															
No.	HydroCode	Length	Drain Area (Mi^2)	Long. Slope	Main Channel				Lower Floodplain			Upper Floodplain		
					Flow	Bottom Width	Depth	Top Width	Flow	Depth	Top Width	Flow	Depth	Top Width
28	Sandies Creek	13,030.92	183.19	0.0009	146.48	2.15	5.37	29.01	1,131.17	6.63	121.77	7,074.02	4.29	2,282.50
29	Sandies Creek	3,600.16	285.64	0.0008	228.40	3.40	6.32	34.99	1,763.79	7.97	146.57	11,030.19	5.16	2,747.22
30	Sandies Creek	18,659.16	331.30	0.0004	264.91	3.90	7.60	41.88	2,045.72	9.54	175.51	12,793.30	6.18	3,289.70
31	Sandies Creek	3,673.11	332.65	0.0008	265.99	3.95	6.65	37.22	2,054.08	8.47	155.77	12,845.55	5.48	2,919.71
32	Dykes Creek	4,050.32	1.74	0.0054	1.39	0.00	0.72	3.62	10.73	0.83	15.22	67.08	0.54	285.26
33	Panther Branch	6,529.81	3.26	0.0051	2.61	0.05	0.92	4.64	20.14	1.06	19.54	125.95	0.69	366.20
34	Jack Hand Branch	7,878.42	3.31	0.0046	2.65	0.05	0.94	4.76	20.43	1.09	20.02	127.79	0.70	375.22
35	Panther Branch	4,803.64	12.81	0.0012	10.25	0.15	1.99	10.08	79.12	2.31	42.42	494.82	1.49	795.03
36	Racetrack Creek	5,510.07	3.80	0.0049	3.04	0.05	0.98	4.94	23.45	1.13	20.80	146.62	0.73	389.93
37	Willow Creek	11,134.97	15.90	0.0033	12.71	0.20	1.78	9.10	98.18	2.08	38.28	614.01	1.35	717.56
38	Jack Pump Creek	8,787.90	11.63	0.0040	9.30	0.15	1.53	7.82	71.80	1.79	32.91	448.99	1.16	616.78
39	Corral Creek	3,923.89	1.78	0.0048	1.43	0.00	0.75	3.73	11.01	0.86	15.70	68.87	0.55	294.36
40	Jack Pump Creek	1,619.91	14.14	0.0025	11.31	0.15	1.81	9.21	87.34	2.11	38.74	546.20	1.36	726.06
41	Brushy Creek 3	16,945.71	19.10	0.0042	15.27	0.25	1.82	9.33	117.94	2.14	39.26	737.59	1.38	735.94
42	Mustang Creek	6,091.62	6.74	0.0043	5.39	0.10	1.24	6.29	41.62	1.44	26.48	260.30	0.93	496.26
43	Brushy Creek 3	3,182.68	43.84	0.0003	35.06	0.50	4.04	20.71	270.71	4.74	87.14	1,692.94	3.07	1,633.38
44	Elm Creek	15,606.91	29.46	0.0025	23.56	0.35	2.35	12.10	181.92	2.77	50.89	1,137.66	1.79	953.90
45	Shockley Creek	12,795.83	16.59	0.0025	13.27	0.20	1.91	9.75	102.45	2.23	41.03	640.71	1.44	769.01
46	Elm Creek	915.78	46.30	0.0011	37.02	0.55	3.24	16.74	285.92	3.83	70.42	1,788.03	2.48	1,319.93
47	Elm Creek	6,665.28	107.65	0.0009	86.07	1.25	4.52	23.83	664.69	5.45	100.19	4,156.79	3.53	1,877.89
48	Elm Creek	4,098.77	132.93	0.0010	106.29	1.55	4.77	25.42	820.83	5.81	106.81	5,133.19	3.76	2,001.96
49	Wickey Branch	6,099.10	4.00	0.0049	3.20	0.05	1.00	5.04	24.71	1.15	21.20	154.54	0.75	397.41
50	Elm Creek	1,696.58	139.73	0.0012	111.73	1.65	4.67	25.01	862.81	5.72	105.04	5,395.76	3.70	1,968.78
51	Rusten Branch	2,501.98	1.00	0.0096	0.80	0.00	0.53	2.64	6.16	0.61	11.11	38.54	0.39	208.29
52	Mound Creek	14,163.31	14.71	0.0040	11.76	0.15	1.68	8.53	90.84	1.95	35.87	568.08	1.26	672.35
53	Mound Creek	7,197.20	20.26	0.0017	16.20	0.25	2.22	11.34	125.07	2.60	47.71	782.17	1.68	894.20
54	Board Branch	5,286.55	2.91	0.0040	2.33	0.05	0.92	4.65	17.95	1.07	19.58	112.28	0.69	366.96
55	Mound Creek	1,936.03	25.80	0.0015	20.63	0.30	2.46	12.59	159.28	2.88	52.96	996.11	1.86	992.60
56	Elm Creek	10,146.75	180.64	0.0003	144.44	2.15	6.70	35.67	1,115.45	8.16	149.90	6,975.69	5.28	2,809.61

Upper Sandies and Elm														
No.	HydroCode	Length	Drain Area (Mi^2)	Long. Slope	Main Channel				Lower Floodplain			Upper Floodplain		
					Flow	Bottom Width	Depth	Top Width	Flow	Depth	Top Width	Flow	Depth	Top Width
57	Elm Creek	3,161.64	194.87	0.0009	155.82	2.30	5.45	29.53	1,203.30	6.74	123.93	7,525.08	4.36	2,322.95
58	Cottonwood Creek 2	11,145.29	10.96	0.0038	8.76	0.15	1.52	7.73	67.67	1.77	32.52	423.20	1.14	609.54
59	Elm Creek	4,008.72	209.43	0.0002	167.46	2.50	7.29	38.94	1,293.19	8.90	163.57	8,087.22	5.76	3,065.93
60	Elm Creek	1,500.85	212.09	0.0013	169.59	2.50	5.23	28.63	1,309.61	6.53	120.04	8,189.89	4.23	2,249.96
61	Rocky Creek	20,712.78	26.08	0.0028	20.86	0.30	2.21	11.35	161.07	2.60	47.75	1,007.26	1.68	895.00
62	Elm Creek	2,545.52	239.92	0.0004	191.84	2.85	6.96	37.66	1,481.48	8.60	158.07	9,264.72	5.57	2,962.92

Lower Sandies Watershed														
No.	HydroCode	Length	Drain Area (Mi^2)	Long. Slope	Main Channel				Lower Floodplain			Upper Floodplain		
					Flow	Bottom Width	Depth	Top Width	Flow	Depth	Top Width	Flow	Depth	Top Width
1	Little Cooper Creek	3,975.05	1.33	0.0015	1.06	0.00	0.83	4.15	8.19	0.95	17.47	51.19	0.61	327.36
2	Cooper Creek	6,832.36	4.71	0.0011	3.76	0.05	1.41	7.10	29.07	1.63	29.86	181.82	1.05	559.69
3	Cooper Creek	1,007.62	6.25	0.0019	5.00	0.05	1.41	7.10	38.58	1.63	29.87	241.28	1.05	559.85
4	Anderson Creek	9,212.19	5.42	0.0007	4.34	0.05	1.62	8.14	33.49	1.87	34.26	209.44	1.21	642.18
5	Shoats Creek	25,028.06	27.19	0.0004	21.74	0.30	3.29	16.76	167.90	3.84	70.53	1,049.98	2.48	1,321.95
6	Clear Creek	13,986.03	20.04	0.0007	16.03	0.25	2.64	13.47	123.78	3.09	56.69	774.05	2.00	1,062.59
7	Clear Creek	5,286.44	55.60	0.0005	44.46	0.65	4.05	20.90	343.32	4.79	87.92	2,147.04	3.10	1,647.99
8	Clear Creek	2,451.31	62.79	0.0008	50.21	0.75	3.85	19.98	387.72	4.57	84.02	2,424.70	2.96	1,574.81
9	Clear Creek	2,742.22	71.49	0.0007	57.16	0.85	4.06	21.16	441.43	4.85	88.99	2,760.54	3.13	1,668.02
10	Blackjack Creek	10,102.04	5.73	0.0007	4.58	0.05	1.64	8.24	35.39	1.89	34.65	221.32	1.22	649.43
11	Clear Creek	7,677.78	84.19	0.0004	67.32	1.00	4.86	25.32	519.84	5.80	106.49	3,250.90	3.75	1,996.10
12	Boggie Creek	9,648.21	6.04	0.0009	4.83	0.05	1.59	8.02	37.31	1.84	33.75	233.30	1.19	632.56
13	Birds Creek	9,504.58	11.32	0.0008	9.05	0.15	2.08	10.53	69.89	2.41	44.32	437.06	1.56	830.71
14	Five Mile Creek	15,421.07	23.97	0.0004	19.17	0.30	3.14	15.99	148.00	3.66	67.27	925.56	2.37	1,260.88
15	Sadberry Creek	6,673.43	3.51	0.0007	2.81	0.05	1.38	6.97	21.70	1.60	29.31	135.72	1.03	549.37
16	Five Mile Creek	4,059.30	31.00	0.0004	24.79	0.35	3.34	17.03	191.42	3.90	71.67	1,197.11	2.52	1,343.27
17	Brushy Creek 2	11,176.35	10.56	0.0004	8.44	0.10	2.28	11.49	65.21	2.63	48.36	407.79	1.70	906.37
18	Five Mile Creek	6,443.57	52.00	0.0003	41.58	0.60	4.21	21.65	321.12	4.96	91.07	2,008.17	3.21	1,707.07

Lower Sandies Watershed															
No.	HydroCode	Length	Drain Area (Mi^2)	Long. Slope	Main Channel				Lower Floodplain			Upper Floodplain		
					Flow	Bottom Width	Depth	Top Width	Flow	Depth	Top Width	Flow	Depth	Top Width
19	Brushy Creek 1	15,948.19	10.97	0.0003	8.77	0.05	2.41	12.08	67.76	2.77	50.82	423.72	1.79	952.49
20	Buckhorn Creek	13,117.32	12.27	0.0005	9.81	0.15	2.34	11.86	75.78	2.72	49.89	473.87	1.76	935.17
21	Alligator Creek	7,349.19	2.60	0.0006	2.08	0.05	1.27	6.38	16.05	1.46	26.83	100.34	0.94	502.98
22	Sugar Creek	16,415.50	10.19	0.0005	8.15	0.10	2.17	10.96	62.94	2.51	46.11	393.62	1.62	864.36
23	Liberty Creek	8,223.40	3.98	0.0007	3.18	0.05	1.45	7.32	24.56	1.68	30.80	153.56	1.08	577.35
24	Cottonwood Creek 1	5,349.30	4.09	0.0007	3.27	0.05	1.48	7.43	25.26	1.70	31.24	157.98	1.10	585.54
25	Cottonwood Creek 1	3,149.16	9.20	0.0007	7.36	0.10	1.95	9.83	56.81	2.25	41.38	355.27	1.46	775.56
26	Turkey Creek	4,909.21	2.96	0.0008	2.37	0.05	1.24	6.27	18.29	1.44	26.36	114.39	0.93	494.13
27	Cottonwood Creek 1	7,564.40	18.70	0.0004	14.95	0.20	2.86	14.48	115.47	3.32	60.93	722.13	2.14	1,142.00
28	Sugar Creek	3,400.15	29.97	0.0006	23.96	0.35	3.09	15.78	185.05	3.61	66.39	1,157.24	2.34	1,244.33
29	Sugar Creek	2,343.51	33.87	0.0007	27.08	0.40	3.13	16.03	209.14	3.67	67.45	1,307.89	2.37	1,264.35
30	Salty Creek	7,057.36	53.93	0.0003	43.12	0.65	4.38	22.57	332.98	5.17	94.93	2,082.36	3.34	1,779.29
31	Salty Creek	3,426.99	66.52	0.0006	53.19	0.80	4.18	21.69	410.73	4.97	91.24	2,568.57	3.21	1,710.09
32	Putnam Branch	9,903.08	6.15	0.0005	4.92	0.05	1.80	9.07	37.98	2.08	38.16	237.53	1.34	715.22
33	Salty Creek	11,146.94	89.43	0.0002	71.51	1.05	5.59	29.02	552.20	6.64	122.04	3,453.28	4.30	2,287.57
34	Five Mile Creek	12,833.61	160.52	0.0002	128.35	1.90	7.01	36.96	991.17	8.46	155.37	6,198.49	5.47	2,912.30
35	White Oak Branch	7,276.80	4.92	0.0007	3.94	0.05	1.57	7.90	30.40	1.81	33.26	190.09	1.17	623.34
36	Sandies Creek	14,504.56	377.55	0.0005	301.89	4.45	7.67	42.78	2,331.32	9.74	179.08	14,579.35	6.30	3,356.75
37	Sandies Creek	4,134.26	383.66	0.0005	306.77	4.55	7.76	43.34	2,369.04	9.86	181.41	14,815.24	6.39	3,400.41
38	Sandies Creek	4,573.94	549.29	0.0005	439.21	6.50	8.56	49.31	3,391.78	11.17	205.65	21,211.11	7.24	3,854.82
39	Sandies Creek	3,035.90	554.55	0.0007	443.42	6.55	7.99	46.50	3,424.29	10.51	193.65	21,414.46	6.82	3,629.80
40	Sandies Creek	7,541.69	576.54	0.0003	461.00	6.80	9.61	54.87	3,560.03	12.45	229.13	22,263.32	8.07	4,294.78
41	Sandies Creek	5,003.07	587.03	0.0004	469.39	6.95	9.37	53.82	3,624.83	12.20	224.57	22,668.55	7.91	4,209.45
42	Sandies Creek	7,791.08	678.81	0.0003	542.78	8.05	10.08	58.46	4,191.56	13.22	243.60	26,212.74	8.58	4,566.01
43	Sandies Creek	4,679.80	681.90	0.0006	545.25	8.05	8.90	52.54	4,210.65	11.84	218.37	26,332.10	7.69	4,093.22
44	Deer Creek	16,042.83	24.72	0.0006	19.76	0.30	2.94	15.02	152.62	3.44	63.20	954.47	2.22	1,184.53
45	Sandies Creek	5,733.61	711.24	0.0005	568.71	8.40	9.32	55.01	4,391.80	12.40	228.66	27,464.94	8.05	4,286.05

Appendix D

NCDC daily storm totals were evaluated against NEXRAD storm totals for each storm with a daily value greater than ½ inch according to the Cheapside NCDC rain gauge. NEXRAD totals were averaged across the 10 closest subbasins to the Cheapside station and aggregated for the 24 hours from 7 am to 7am. (See Figure D.1) An evaluation of OK was given for NEXRAD storms that came within +/- 20% of the NCDC storms.

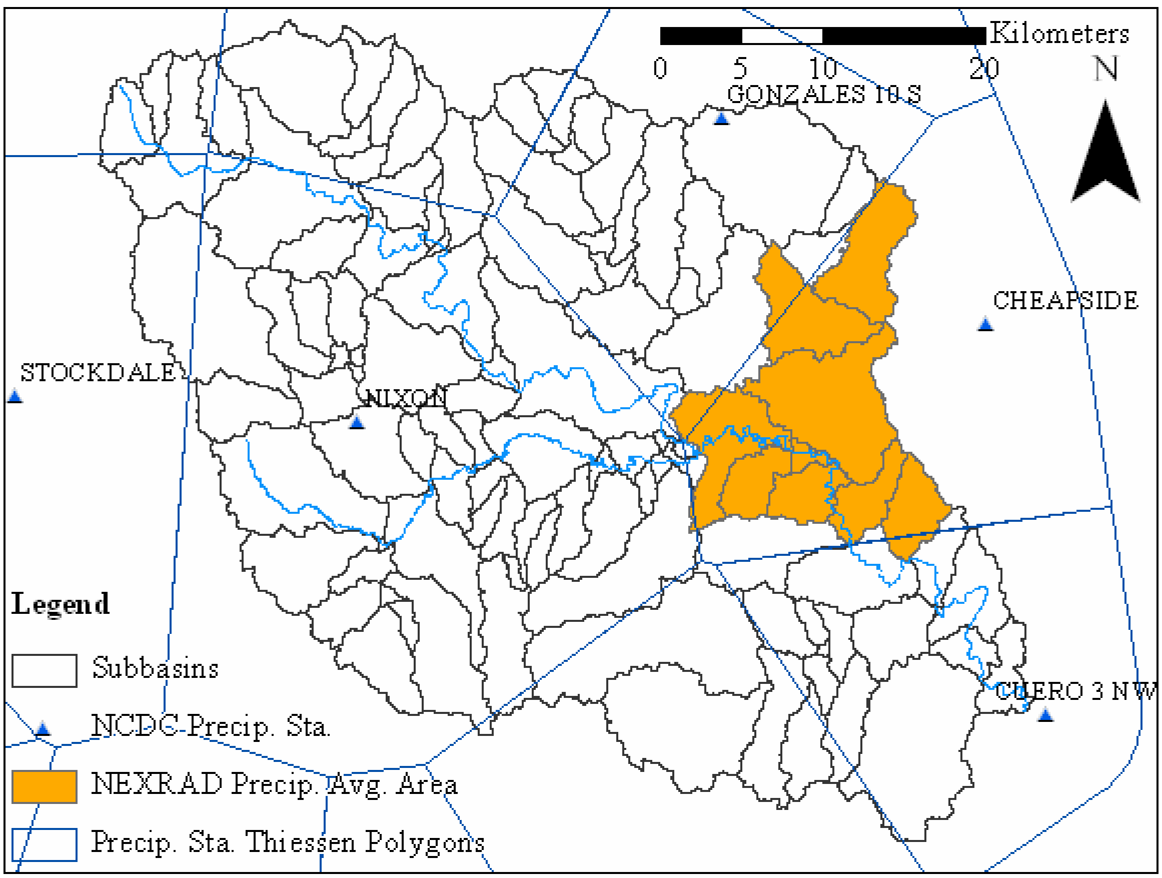


Figure D.1: Precipitation Stations, Thiessen Polygons, and Comparison Area

Table D.1: Significant Storm Comparison - 2000

Date	NCDC (In)	NEXRAD (in)	Difference	Evaluation	Note
1/7/2000	0.86	0.44	2.0	NG	
1/8/2000	2.45	0.79	3.1	NG	
1/28/2000	0.81	0.10	8.3	NG	
2/23/2000	2.24	2.42	0.9	OK	
3/15/2000	1.92	0.82	2.3	OK	storm totals add up
4/3/2000	0.68	0.92	0.7	NG	
5/1/2000	0.5	0.76	0.7	NG	
5/2/2000	1.65	2.08	0.8	OK	
5/3/2000	0.7	0.00	100.0	OK	storm totals add up
5/13/2000	0.9	0.92	1.0	OK	
5/20/2000	0.84	1.36	0.6	NG	
6/5/2000	1.42	1.89	0.8	OK	
6/9/2000	0.76	0.84	0.9	OK	
6/10/2000	1.8	1.89	1.0	OK	
6/11/2000	1.5	1.27	1.2	OK	
8/22/2000	0.53	0.20	2.7	OK	storm totals add up
9/22/2000	1.67	1.41	1.2	OK	
9/25/2000	0.51	0.50	1.0	OK	
10/8/2000	1.15	0.00	100.0	NG	
10/10/2000	0.62	0.00	100.0	NG	
10/22/2000	0.58	1.20	0.5	NG	
10/23/2000	0.88	0.30	2.9	NG	
11/4/2000	2.25	2.20	1.0	OK	
11/6/2000	1.33	0.00	100.0	NG	
11/18/2000	1.44	0.00	100.0	NG	
11/19/2000	1.27	0.00	100.0	NG	
11/24/2000	1.05	0.00	100.0	NG	
12/13/2000	0.75	0.00	100.0	NG	

Table D.2: Significant Storm Comparison - 2001

Date	NCDC (In)	NEXRAD (in)	Difference	Evaluation	Note
1/11/2001	0.99	0.00	100.0	OK	storm totals add up
3/2/2001	1.77	0.73	2.4	NG	
3/3/2001	0.64	0.30	2.2	NG	
3/4/2001	0.77	0.40	1.9	NG	
3/15/2001	1.72	1.23	1.4	NG	
5/5/2001	1.1	0.49	2.2	NG	
6/9/2001	0.54	0.49	1.1	OK	
8/30/2001	2.34	1.85	1.3	NG	
8/31/2001	8.6	8.83	1.0	OK	
9/1/2001	1.8	0.00	514.3	OK	storm totals add up
9/2/2001	1.05	0.28	3.8	OK	storm totals add up
9/6/2001	0.85	1.08	0.8	OK	
9/10/2001	2.12	0.13	16.1	NG	
10/6/2001	0.89	0.55	1.6	NG	
10/13/2001	1.52	1.56	1.0	OK	
11/29/2001	0.6	0.55	1.1	OK	
12/2/2001	0.71	1.70	0.4	NG	
12/3/2001	2.55	1.28	2.0	OK	storm totals add up
12/8/2001	0.71	0.63	1.1	OK	
12/12/2001	0.67	0.53	1.3	NG	
12/16/2001	0.64	0.19	3.4	NG	

Table D.3: Significant Storm Comparison - 2002

Date	NCDC (In)	NEXRAD (in)	Difference	Evaluation	Note
3/20/2002	0.89	0.95	0.9	OK	
4/8/2002	2.88	2.40	1.2	OK	
5/28/2002	1.48	0.59	2.5	NG	
6/16/2002	0.64	0.97	0.7	NG	
6/21/2002	0.91	0.11	8.1	NG	
6/27/2002	1.3	1.96	0.7	NG	
6/30/2002	2.31	2.57	0.9	OK	
7/2/2002	1.95	2.60	0.7	NG	
7/3/2002	1.25	2.18	0.6	NG	
7/10/2002	0.84	0.82	1.0	OK	
7/15/2002	1.35	4.69	0.3	NG	
7/16/2002	1.22	1.61	0.8	OK	
7/17/2002	1.33	0.40	3.3	NG	
8/15/2002	0.61	0.34	1.8	NG	
8/16/2002	1.05	0.14	7.5	NG	
9/7/2002	1.98	0.93	2.1	OK	storm totals add up
9/8/2002	1.24	2.55	0.5	OK	storm totals add up
9/9/2002	0.63	0.21	3.0	OK	storm totals add up
10/8/2002	0.87	0.39	2.2	OK	storm totals add up
10/9/2002	0.77	0.97	0.8	OK	storm totals add up
10/23/2002	2.55	1.40	1.8	OK	storm totals add up
10/25/2002	1.36	1.13	1.2	OK	
11/3/2002	0.79	0.84	0.9	OK	
11/4/2002	1.4	1.86	0.8	OK	
11/5/2002	2.4	1.13	2.1	OK	storm totals add up
12/5/2002	0.98	0.72	1.4	OK	storm totals add up
12/9/2002	0.86	1.58	0.5	NG	
12/10/2002	1.1	0.23	4.9	NG	
12/13/2002	2.86	0.00	100.0	OK	storm totals add up
12/24/2002	2.38	1.10	2.2	NG	
12/31/2002	1.1	1.00	1.1	OK	

Table D.4: Significant Storm Comparison - 2003

Date	NCDC (In)	NEXRAD (in)	Difference	Evaluation	Note
1/12/2003	0.88	1.32	0.7	NG	
1/13/2003	0.85	0.26	3.3	NG	
2/21/2003	1.52	0.35	4.4	NG	
6/4/2003	0.97	0.61	1.6	OK	storm totals add up
6/6/2003	0.63	0.60	1.0	OK	
6/14/2003	1.05	1.00	1.1	OK	
7/5/2003	1.17	1.48	0.8	OK	
7/8/2003	0.71	0.15	4.8	OK	storm totals add up
7/9/2003	0.61	0.46	1.3	NG	
7/16/2003	1.71	2.05	0.8	OK	
7/17/2003	1.01	0.17	5.8	OK	storm totals add up
7/28/2003	0.59	0.03	20.3	NG	
8/9/2003	0.79	0.62	1.3	NG	
8/12/2003	1.54	0.88	1.7	NG	
8/17/2003	0.52	0.22	2.4	NG	
9/2/2003	3.1	3.51	0.9	OK	
9/3/2003	0.63	0.07	8.8	OK	storm totals add up
9/12/2003	1.47	1.92	0.8	OK	
9/19/2003	1.05	0.53	2.0	NG	
9/21/2003	1.37	0.37	3.7	NG	
10/26/2003	0.87	0.57	1.5	NG	
11/18/2003	0.64	0.25	2.6	NG	
12/13/2003	0.83	0.40	2.1	OK	storm totals add up
12/29/2003	1.03	0.75	1.4	NG	

Table D.5: Significant Storm Comparison - 2004

Date	NCDC (In)	NEXRAD (in)	Difference	Evaluation	Note
1/17/2004	1.75	1.05	1.7	NG	
1/25/2004	0.78	0.54	1.4	NG	
2/11/2004	1.4	0.15	9.6	NG	
3/14/2004	0.6	0.14	4.2	NG	
4/3/2004	0.59	0.64	0.9	OK	
4/11/2004	1.37	1.12	1.2	OK	
4/24/2004	0.91	0.70	1.3	NG	
4/26/2004	0.53	0.10	5.4	OK	storm totals add up
4/29/2004	0.7	0.71	1.0	OK	
5/2/2004	0.51	0.01	50.1	OK	storm totals add up
5/12/2004	0.82	0.64	1.3	NG	
5/14/2004	2.35	1.76	1.3	NG	
6/5/2004	1.23	0.86	1.4	NG	
6/8/2004	1.79	0.91	2.0	NG	
6/9/2004	0.75	0.10	7.6	NG	
6/16/2004	0.56	0.61	0.9	OK	
6/26/2004	1.51	1.00	1.5	OK	storm totals add up
7/1/2004	1.31	0.83	1.6	OK	storm totals add up
7/24/2004	0.94	0.18	5.2	NG	
7/30/2004	1.05	1.40	0.7	NG	
8/22/2004	0.64	0.43	1.5	OK	storm totals add up
9/14/2004	1.08	0.73	1.5	NG	
9/15/2004	0.96	0.43	2.2	NG	
10/3/2004	1.63	0.33	5.0	NG	
10/7/2004	1.16	0.15	7.8	NG	
10/14/2004	1.5	1.46	1.0	OK	
10/24/2004	1.23	0.00	448.9	OK	storm totals add up
11/1/2004	1.14	1.11	1.0	OK	
11/17/2004	0.71	1.83	0.4	NG	
11/18/2004	1.46	0.05	31.0	OK	storm totals add up
11/21/2004	1.5	1.42	1.1	OK	
11/22/2004	0.86	1.81	0.5	NG	
11/23/2004	1.06	0.81	1.3	NG	

Appendix E: Model Parameters

UPPER SANDIES

PWATER – PARAMETER SET 2

*** < PLS> *** x	- x	FOREST	LZSN (in)	INFILT (in/hr)	LSUR (ft)	SLSUR	KVARY (1/in)	AGWRC (1/day)
11		0.	6.2	0.01	726.	0.042	0.	0.999
12	16	0.	6.2	0.02	726	0.042	0.	0.999
21		0.	6.2	0.01	663.	0.039	0.	0.999
22	26	0.	6.2	0.03	663.	0.039	0.	0.999
31		0.	6.2	0.01	686.	0.037	0.	0.999
32	36	0.	6.2	0.03	686.	0.037	0.	0.999
41		0.	6.2	0.01	845.	0.04	0.	0.999
42	46	0.	6.2	0.02	845.	0.04	0.	0.999
51		0.	6.2	0.01	479.	0.043	0.	0.999
52	56	0.	6.2	0.03	479.	0.043	0.	0.999
61		0.	6.2	0.01	849.	0.044	0.	0.999
62	66	0.	6.2	0.03	849.	0.044	0.	0.999
71		0.	6.2	0.01	1859.	0.046	0.	0.999
72	76	0.	6.2	0.03	1859.	0.046	0.	0.999
81		0.	6.2	0.01	1865.	0.083	0.	0.999
82	86	0.	6.2	0.03	1865.	0.083	0.	0.999
91		0.	6.2	0.01	691.	0.039	0.	0.999
92	96	0.	6.2	0.03	691.	0.039	0.	0.999
101		0.	6.2	0.01	837.	0.037	0.	0.999
102	106	0.	6.2	0.02	837.	0.037	0.	0.999
111		0.	6.2	0.01	546.	0.048	0.	0.999
112	116	0.	6.2	0.03	546.	0.048	0.	0.999
121		0.	6.2	0.01	700.	0.073	0.	0.999
122	126	0.	6.2	0.06	700.	0.073	0.	0.999
131		0.	6.2	0.01	739.	0.057	0.	0.999
132	136	0.	6.2	0.06	739.	0.057	0.	0.999
141		0.	6.2	0.01	688.	0.046	0.	0.999
142	146	0.	6.2	0.06	688.	0.046	0.	0.999
151		0.	6.2	0.01	760.	0.062	0.	0.999
152	156	0.	6.2	0.06	760.	0.062	0.	0.999
161		0.	6.2	0.01	564.	0.031	0.	0.999
162	166	0.	6.2	0.06	564.	0.031	0.	0.999
171		0.	6.2	0.01	717.	0.043	0.	0.999
172	176	0.	6.2	0.03	717.	0.043	0.	0.999
181		0.	6.2	0.01	924.	0.047	0.	0.999
182	186	0.	6.2	0.03	924.	0.047	0.	0.999
191		0.	6.2	0.01	723.	0.036	0.	0.999
192	196	0.	6.2	0.06	723.	0.036	0.	0.999
201		0.	6.2	0.01	652.	0.045	0.	0.999
202	206	0.	6.2	0.06	652.	0.045	0.	0.999
211		0.	6.2	0.01	1027.	0.036	0.	0.999
212	215	0.	6.2	0.03	1027.	0.036	0.	0.999
221		0.	6.2	0.01	1057.	0.05	0.	0.999
222	226	0.	6.2	0.03	1057.	0.05	0.	0.999
231		0.	6.2	0.01	1177.	0.035	0.	0.999
232	236	0.	6.2	0.03	1177.	0.035	0.	0.999
241		0.	6.2	0.01	941.	0.048	0.	0.999
242	246	0.	6.2	0.03	941.	0.048	0.	0.999
251		0.	6.2	0.01	974.	0.027	0.	0.999
252	256	0.	6.2	0.03	974.	0.027	0.	0.999
261		0.	6.2	0.01	1061.	0.042	0.	0.999
262	265	0.	6.2	0.03	1061.	0.042	0.	0.999
271		0.	6.2	0.01	877.	0.04	0.	0.999
272	276	0.	6.2	0.03	877.	0.04	0.	0.999

*** < PLS>		FOREST	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
*** x	- x		(in)	(in/hr)	(ft)		(1/in)	(1/day)
281		0.	6.2	0.01	757.	0.037	0.	0.999
282	286	0.	6.2	0.02	757.	0.037	0.	0.999
291	296	0.	6.2	0.01	1201.	0.062	0.	0.999
301		0.	6.2	0.01	868.	0.033	0.	0.999
302	306	0.	6.2	0.02	868.	0.033	0.	0.999
312	316	0.	6.2	0.03	1069.	0.082	0.	0.999
322	326	0.	6.2	0.03	1013.	0.078	0.	0.999
332	336	0.	6.2	0.03	683.	0.058	0.	0.999
342	346	0.	6.2	0.03	935.	0.076	0.	0.999
351		0.	6.2	0.01	1366.	0.045	0.	0.999
352	356	0.	6.2	0.03	1366.	0.045	0.	0.999
361	366	0.	6.2	0.01	842.	0.055	0.	0.999
371	376	0.	6.2	0.01	865.	0.038	0.	0.999
381		0.	6.2	0.01	830.	0.039	0.	0.999
382	386	0.	6.2	0.03	830.	0.039	0.	0.999
391		0.	6.2	0.01	745.	0.072	0.	0.999
392	396	0.	6.2	0.03	745.	0.072	0.	0.999
401	405	0.	6.2	0.01	2051.	0.058	0.	0.999
411		0.	6.2	0.01	691.	0.045	0.	0.999
412	416	0.	6.2	0.03	691.	0.045	0.	0.999
421	426	0.	6.2	0.01	940.	0.037	0.	0.999
431	436	0.	6.2	0.01	876.	0.038	0.	0.999
441		0.	6.2	0.01	663.	0.028	0.	0.999
442	446	0.	6.2	0.02	663.	0.028	0.	0.999
451	456	0.	6.2	0.01	688.	0.037	0.	0.999
462	465	0.	6.2	0.02	2973.	0.079	0.	0.999
471		0.	6.2	0.01	886.	0.036	0.	0.999
472	476	0.	6.2	0.02	886.	0.036	0.	0.999
481	486	0.	6.2	0.01	1398.	0.04	0.	0.999
491	496	0.	6.2	0.01	671.	0.055	0.	0.999
501	506	0.	6.2	0.01	1031.	0.03	0.	0.999
511		0.	6.2	0.01	757.	0.086	0.	0.999
512	516	0.	6.2	0.03	757.	0.086	0.	0.999
521		0.	6.2	0.01	685.	0.05	0.	0.999
522	526	0.	6.2	0.03	685.	0.05	0.	0.999
531		0.	6.2	0.01	1268.	0.055	0.	0.999
532	536	0.	6.2	0.03	1268.	0.055	0.	0.999
542	546	0.	6.2	0.02	757.	0.056	0.	0.999
551	556	0.	6.2	0.01	1486.	0.037	0.	0.999
561	566	0.	6.2	0.01	993.	0.033	0.	0.999
572	576	0.	6.2	0.02	1056.	0.063	0.	0.999
581		0.	6.2	0.01	1039.	0.054	0.	0.999
582	586	0.	6.2	0.03	1039.	0.054	0.	0.999
591		0.	6.2	0.01	1117.	0.042	0.	0.999
592	596	0.	6.2	0.02	1117.	0.042	0.	0.999
601		0.	6.2	0.01	1509.	0.059	0.	0.999
602	606	0.	6.2	0.03	1509.	0.059	0.	0.999
611		0.	6.2	0.01	956.	0.048	0.	0.999
612	616	0.	6.2	0.02	956.	0.048	0.	0.999
621		0.	6.2	0.01	2377.	0.055	0.	0.999
622	626	0.	6.2	0.03	2377.	0.055	0.	0.999

PWater – Parameter Set 3

*** < PLS>		PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
*** x	- x	(deg F)	(deg F)					
11	15	0.	0.	2.	2.	0.	0.	0.
16		0.	0.	2.	2.	0.	0.	0.05
21	25	0.	0.	2.	2.	0.	0.	0.
26		0.	0.	2.	2.	0.	0.	0.05
31	35	0.	0.	2.	2.	0.	0.	0.
36		0.	0.	2.	2.	0.	0.	0.05
41	45	0.	0.	2.	2.	0.	0.	0.
46		0.	0.	2.	2.	0.	0.	0.05

*** < PLS>		PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
*** x	- x	(deg F)	(deg F)					
51	55	0.	0.	2.	2.	0.	0.	0.
56		0.	0.	2.	2.	0.	0.	0.05
61	65	0.	0.	2.	2.	0.	0.	0.
66		0.	0.	2.	2.	0.	0.	0.05
71	75	0.	0.	2.	2.	0.	0.	0.
76		0.	0.	2.	2.	0.	0.	0.05
81	85	0.	0.	2.	2.	0.	0.	0.
86		0.	0.	2.	2.	0.	0.	0.05
91	95	0.	0.	2.	2.	0.	0.	0.
96		0.	0.	2.	2.	0.	0.	0.05
101	105	0.	0.	2.	2.	0.	0.	0.
106		0.	0.	2.	2.	0.	0.	0.05
111	115	0.	0.	2.	2.	0.	0.	0.
116		0.	0.	2.	2.	0.	0.	0.05
121	125	0.	0.	2.	2.	0.	0.	0.
126		0.	0.	2.	2.	0.	0.	0.05
131	135	0.	0.	2.	2.	0.	0.	0.
136		0.	0.	2.	2.	0.	0.	0.05
141	145	0.	0.	2.	2.	0.	0.	0.
146		0.	0.	2.	2.	0.	0.	0.05
151	155	0.	0.	2.	2.	0.	0.	0.
156		0.	0.	2.	2.	0.	0.	0.05
161	165	0.	0.	2.	2.	0.	0.	0.
166		0.	0.	2.	2.	0.	0.	0.05
171	175	0.	0.	2.	2.	0.	0.	0.
176		0.	0.	2.	2.	0.	0.	0.05
181	185	0.	0.	2.	2.	0.	0.	0.
186		0.	0.	2.	2.	0.	0.	0.05
191	195	0.	0.	2.	2.	0.	0.	0.
196		0.	0.	2.	2.	0.	0.	0.05
201	205	0.	0.	2.	2.	0.	0.	0.
206		0.	0.	2.	2.	0.	0.	0.05
211	225	0.	0.	2.	2.	0.	0.	0.
226		0.	0.	2.	2.	0.	0.	0.05
231	235	0.	0.	2.	2.	0.	0.	0.
236		0.	0.	2.	2.	0.	0.	0.05
241	245	0.	0.	2.	2.	0.	0.	0.
246		0.	0.	2.	2.	0.	0.	0.05
251	255	0.	0.	2.	2.	0.	0.	0.
256		0.	0.	2.	2.	0.	0.	0.05
261	275	0.	0.	2.	2.	0.	0.	0.
276		0.	0.	2.	2.	0.	0.	0.05
281	285	0.	0.	2.	2.	0.	0.	0.
286		0.	0.	2.	2.	0.	0.	0.05
291	295	0.	0.	2.	2.	0.	0.	0.
296		0.	0.	2.	2.	0.	0.	0.05
301	305	0.	0.	2.	2.	0.	0.	0.
306		0.	0.	2.	2.	0.	0.	0.05
312	315	0.	0.	2.	2.	0.	0.	0.
316		0.	0.	2.	2.	0.	0.	0.05
322	325	0.	0.	2.	2.	0.	0.	0.
326		0.	0.	2.	2.	0.	0.	0.05
332	335	0.	0.	2.	2.	0.	0.	0.
336		0.	0.	2.	2.	0.	0.	0.05
342	345	0.	0.	2.	2.	0.	0.	0.
346		0.	0.	2.	2.	0.	0.	0.05
351	355	0.	0.	2.	2.	0.	0.	0.
356		0.	0.	2.	2.	0.	0.	0.05
361	365	0.	0.	2.	2.	0.	0.	0.
366		0.	0.	2.	2.	0.	0.	0.05
371	375	0.	0.	2.	2.	0.	0.	0.
376		0.	0.	2.	2.	0.	0.	0.05
381	385	0.	0.	2.	2.	0.	0.	0.
386		0.	0.	2.	2.	0.	0.	0.05
391	395	0.	0.	2.	2.	0.	0.	0.
396		0.	0.	2.	2.	0.	0.	0.05

*** < PLS>		PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
*** x	- x	(deg F)	(deg F)					
401	415	0.	0.	2.	2.	0.	0.	0.
416		0.	0.	2.	2.	0.	0.	0.05
421	425	0.	0.	2.	2.	0.	0.	0.
426		0.	0.	2.	2.	0.	0.	0.05
431	435	0.	0.	2.	2.	0.	0.	0.
436		0.	0.	2.	2.	0.	0.	0.05
441	445	0.	0.	2.	2.	0.	0.	0.
446		0.	0.	2.	2.	0.	0.	0.05
451	455	0.	0.	2.	2.	0.	0.	0.
456		0.	0.	2.	2.	0.	0.	0.05
462	475	0.	0.	2.	2.	0.	0.	0.
476		0.	0.	2.	2.	0.	0.	0.05
481	485	0.	0.	2.	2.	0.	0.	0.
486		0.	0.	2.	2.	0.	0.	0.05
491	495	0.	0.	2.	2.	0.	0.	0.
496		0.	0.	2.	2.	0.	0.	0.05
501	505	0.	0.	2.	2.	0.	0.	0.
506		0.	0.	2.	2.	0.	0.	0.05
511	515	0.	0.	2.	2.	0.	0.	0.
516		0.	0.	2.	2.	0.	0.	0.05
521	525	0.	0.	2.	2.	0.	0.	0.
526		0.	0.	2.	2.	0.	0.	0.05
531	535	0.	0.	2.	2.	0.	0.	0.
536		0.	0.	2.	2.	0.	0.	0.05
542	545	0.	0.	2.	2.	0.	0.	0.
546		0.	0.	2.	2.	0.	0.	0.05
551	555	0.	0.	2.	2.	0.	0.	0.
556		0.	0.	2.	2.	0.	0.	0.05
561	565	0.	0.	2.	2.	0.	0.	0.
566		0.	0.	2.	2.	0.	0.	0.05
572	575	0.	0.	2.	2.	0.	0.	0.
576		0.	0.	2.	2.	0.	0.	0.05
581	585	0.	0.	2.	2.	0.	0.	0.
586		0.	0.	2.	2.	0.	0.	0.05
591	595	0.	0.	2.	2.	0.	0.	0.
596		0.	0.	2.	2.	0.	0.	0.05
601	605	0.	0.	2.	2.	0.	0.	0.
606		0.	0.	2.	2.	0.	0.	0.05
611	615	0.	0.	2.	2.	0.	0.	0.
616		0.	0.	2.	2.	0.	0.	0.05
621	625	0.	0.	2.	2.	0.	0.	0.
626		0.	0.	2.	2.	0.	0.	0.05

PWater – Parameter Set 4

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
11	0	0.10	0.1	4.0	0.55	0
12	0.15	0.10	0.35	4.0	0.55	0.4
13	0.1	0.10	0.3	4.0	0.55	0.3
14	0.1	0.10	0.2	4.0	0.55	0.1
15	0.15	0.10	0.25	4.0	0.55	0.2
16	0.1	0.10	0.05	4.0	0.55	0.4
21	0	0.10	0.1	4.0	0.55	0
22	0.15	0.10	0.35	4.0	0.55	0.4
23	0.1	0.10	0.3	4.0	0.55	0.3
24	0.1	0.10	0.2	4.0	0.55	0.1
25	0.15	0.10	0.25	4.0	0.55	0.2
26	0.1	0.10	0.05	4.0	0.55	0.4
31	0	0.10	0.1	4.0	0.55	0
32	0.15	0.10	0.35	4.0	0.55	0.4
33	0.1	0.10	0.3	4.0	0.55	0.3
34	0.1	0.10	0.2	4.0	0.55	0.1
35	0.15	0.10	0.25	4.0	0.55	0.2

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
36	0.1	0.10	0.05	4.0	0.55	0.4
41	0	0.10	0.1	4.0	0.55	0
42	0.15	0.10	0.35	4.0	0.55	0.4
43	0.1	0.10	0.3	4.0	0.55	0.3
44	0.1	0.10	0.2	4.0	0.55	0.1
45	0.15	0.10	0.25	4.0	0.55	0.2
46	0.1	0.10	0.05	4.0	0.55	0.4
51	0	0.10	0.1	4.0	0.55	0
52	0.15	0.10	0.35	4.0	0.55	0.4
53	0.1	0.10	0.3	4.0	0.55	0.3
54	0.1	0.10	0.2	4.0	0.55	0.1
55	0.15	0.10	0.25	4.0	0.55	0.2
56	0.1	0.10	0.05	4.0	0.55	0.4
61	0	0.10	0.1	4.0	0.55	0
62	0.15	0.10	0.35	4.0	0.55	0.4
63	0.1	0.10	0.3	4.0	0.55	0.3
64	0.1	0.10	0.2	4.0	0.55	0.1
65	0.15	0.10	0.25	4.0	0.55	0.2
66	0.1	0.10	0.05	4.0	0.55	0.4
71	0	0.10	0.1	4.0	0.55	0
72	0.15	0.10	0.35	4.0	0.55	0.4
73	0.1	0.10	0.3	4.0	0.55	0.3
74	0.1	0.10	0.2	4.0	0.55	0.1
75	0.15	0.10	0.25	4.0	0.55	0.2
76	0.1	0.10	0.05	4.0	0.55	0.4
81	0	0.10	0.1	4.0	0.55	0
82	0.15	0.10	0.35	4.0	0.55	0.4
83	0.1	0.10	0.3	4.0	0.55	0.3
84	0.1	0.10	0.2	4.0	0.55	0.1
85	0.15	0.10	0.25	4.0	0.55	0.2
86	0.1	0.10	0.05	4.0	0.55	0.4
91	0	0.10	0.1	4.0	0.55	0
92	0.15	0.10	0.35	4.0	0.55	0.4
93	0.1	0.10	0.3	4.0	0.55	0.3
94	0.1	0.10	0.2	4.0	0.55	0.1
95	0.15	0.10	0.25	4.0	0.55	0.2
96	0.1	0.10	0.05	4.0	0.55	0.4
101	0	0.10	0.1	4.0	0.55	0
102	0.15	0.10	0.35	4.0	0.55	0.4
103	0.1	0.10	0.3	4.0	0.55	0.3
104	0.1	0.10	0.2	4.0	0.55	0.1
105	0.15	0.10	0.25	4.0	0.55	0.2
106	0.1	0.10	0.05	4.0	0.55	0.4
111	0	0.10	0.1	4.0	0.55	0
112	0.15	0.10	0.35	4.0	0.55	0.4
113	0.1	0.10	0.3	4.0	0.55	0.3
114	0.1	0.10	0.2	4.0	0.55	0.1
115	0.15	0.10	0.25	4.0	0.55	0.2
116	0.1	0.10	0.05	4.0	0.55	0.4
121	0	0.10	0.1	4.0	0.55	0
122	0.15	0.10	0.35	4.0	0.55	0.4
123	0.1	0.10	0.3	4.0	0.55	0.3
124	0.1	0.10	0.2	4.0	0.55	0.1
125	0.15	0.10	0.25	4.0	0.55	0.2
126	0.1	0.10	0.05	4.0	0.55	0.4
131	0	0.10	0.1	4.0	0.55	0
132	0.15	0.10	0.35	4.0	0.55	0.4
133	0.1	0.10	0.3	4.0	0.55	0.3
134	0.1	0.10	0.2	4.0	0.55	0.1
135	0.15	0.10	0.25	4.0	0.55	0.2
136	0.1	0.10	0.05	4.0	0.55	0.4
141	0	0.10	0.1	4.0	0.55	0
142	0.15	0.10	0.35	4.0	0.55	0.4
143	0.1	0.10	0.3	4.0	0.55	0.3
144	0.1	0.10	0.2	4.0	0.55	0.1
145	0.15	0.10	0.25	4.0	0.55	0.2

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
146	0.1	0.10	0.05	4.0	0.55	0.4
151	0	0.10	0.1	4.0	0.55	0
152	0.15	0.10	0.35	4.0	0.55	0.4
153	0.1	0.10	0.3	4.0	0.55	0.3
154	0.1	0.10	0.2	4.0	0.55	0.1
155	0.15	0.10	0.25	4.0	0.55	0.2
156	0.1	0.10	0.05	4.0	0.55	0.4
161	0	0.10	0.1	4.0	0.55	0
162	0.15	0.10	0.35	4.0	0.55	0.4
163	0.1	0.10	0.3	4.0	0.55	0.3
164	0.1	0.10	0.2	4.0	0.55	0.1
165	0.15	0.10	0.25	4.0	0.55	0.2
166	0.1	0.10	0.05	4.0	0.55	0.4
171	0	0.10	0.1	4.0	0.55	0
172	0.15	0.10	0.35	4.0	0.55	0.4
173	0.1	0.10	0.3	4.0	0.55	0.3
174	0.1	0.10	0.2	4.0	0.55	0.1
175	0.15	0.10	0.25	4.0	0.55	0.2
176	0.1	0.10	0.05	4.0	0.55	0.4
181	0	0.10	0.1	4.0	0.55	0
182	0.15	0.10	0.35	4.0	0.55	0.4
183	0.1	0.10	0.3	4.0	0.55	0.3
184	0.1	0.10	0.2	4.0	0.55	0.1
185	0.15	0.10	0.25	4.0	0.55	0.2
186	0.1	0.10	0.05	4.0	0.55	0.4
191	0	0.10	0.1	4.0	0.55	0
192	0.15	0.10	0.35	4.0	0.55	0.4
193	0.1	0.10	0.3	4.0	0.55	0.3
194	0.1	0.10	0.2	4.0	0.55	0.1
195	0.15	0.10	0.25	4.0	0.55	0.2
196	0.1	0.10	0.05	4.0	0.55	0.4
201	0	0.10	0.1	4.0	0.55	0
202	0.15	0.10	0.35	4.0	0.55	0.4
203	0.1	0.10	0.3	4.0	0.55	0.3
204	0.1	0.10	0.2	4.0	0.55	0.1
205	0.15	0.10	0.25	4.0	0.55	0.2
206	0.1	0.10	0.05	4.0	0.55	0.4
211	0	0.10	0.1	4.0	0.55	0
212	0.15	0.10	0.35	4.0	0.55	0.4
213	0.1	0.10	0.3	4.0	0.55	0.3
214	0.1	0.10	0.2	4.0	0.55	0.1
215	0.15	0.10	0.25	4.0	0.55	0.2
221	0	0.10	0.1	4.0	0.55	0
222	0.15	0.10	0.35	4.0	0.55	0.4
223	0.1	0.10	0.3	4.0	0.55	0.3
224	0.1	0.10	0.2	4.0	0.55	0.1
225	0.15	0.10	0.25	4.0	0.55	0.2
226	0.1	0.10	0.05	4.0	0.55	0.4
231	0	0.10	0.1	4.0	0.55	0
232	0.15	0.10	0.35	4.0	0.55	0.4
233	0.1	0.10	0.3	4.0	0.55	0.3
234	0.1	0.10	0.2	4.0	0.55	0.1
235	0.15	0.10	0.25	4.0	0.55	0.2
236	0.1	0.10	0.05	4.0	0.55	0.4
241	0	0.10	0.1	4.0	0.55	0
242	0.15	0.10	0.35	4.0	0.55	0.4
243	0.1	0.10	0.3	4.0	0.55	0.3
244	0.1	0.10	0.2	4.0	0.55	0.1
245	0.15	0.10	0.25	4.0	0.55	0.2
246	0.1	0.10	0.05	4.0	0.55	0.4
251	0	0.10	0.1	4.0	0.55	0
252	0.15	0.10	0.35	4.0	0.55	0.4
253	0.1	0.10	0.3	4.0	0.55	0.3
254	0.1	0.10	0.2	4.0	0.55	0.1
255	0.15	0.10	0.25	4.0	0.55	0.2
256	0.1	0.10	0.05	4.0	0.55	0.4

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
261	0	0.10	0.1	4.0	0.55	0
262	0.15	0.10	0.35	4.0	0.55	0.4
263	0.1	0.10	0.3	4.0	0.55	0.3
264	0.1	0.10	0.2	4.0	0.55	0.1
265	0.15	0.10	0.25	4.0	0.55	0.2
271	0	0.10	0.1	4.0	0.55	0
272	0.15	0.10	0.35	4.0	0.55	0.4
273	0.1	0.10	0.3	4.0	0.55	0.3
274	0.1	0.10	0.2	4.0	0.55	0.1
275	0.15	0.10	0.25	4.0	0.55	0.2
276	0.1	0.10	0.05	4.0	0.55	0.4
281	0	0.10	0.1	4.0	0.55	0
282	0.15	0.10	0.35	4.0	0.55	0.4
283	0.1	0.10	0.3	4.0	0.55	0.3
284	0.1	0.10	0.2	4.0	0.55	0.1
285	0.15	0.10	0.25	4.0	0.55	0.2
286	0.1	0.10	0.05	4.0	0.55	0.4
291	0	0.10	0.1	4.0	0.55	0
292	0.15	0.10	0.35	4.0	0.55	0.4
293	0.1	0.10	0.3	4.0	0.55	0.3
294	0.1	0.10	0.2	4.0	0.55	0.1
295	0.15	0.10	0.25	4.0	0.55	0.2
296	0.1	0.10	0.05	4.0	0.55	0.4
301	0	0.10	0.1	4.0	0.55	0
302	0.15	0.10	0.35	4.0	0.55	0.4
303	0.1	0.10	0.3	4.0	0.55	0.3
304	0.1	0.10	0.2	4.0	0.55	0.1
305	0.15	0.10	0.25	4.0	0.55	0.2
306	0.1	0.10	0.05	4.0	0.55	0.4
312	0.15	0.10	0.35	4.0	0.55	0.4
313	0.1	0.10	0.3	4.0	0.55	0.3
314	0.1	0.10	0.2	4.0	0.55	0.1
315	0.15	0.10	0.25	4.0	0.55	0.2
316	0.1	0.10	0.05	4.0	0.55	0.4
322	0.15	0.10	0.35	4.0	0.55	0.4
323	0.1	0.10	0.3	4.0	0.55	0.3
324	0.1	0.10	0.2	4.0	0.55	0.1
325	0.15	0.10	0.25	4.0	0.55	0.2
326	0.1	0.10	0.05	4.0	0.55	0.4
332	0.15	0.10	0.35	4.0	0.55	0.4
333	0.1	0.10	0.3	4.0	0.55	0.3
334	0.1	0.10	0.2	4.0	0.55	0.1
335	0.15	0.10	0.25	4.0	0.55	0.2
336	0.1	0.10	0.05	4.0	0.55	0.4
342	0.15	0.10	0.35	4.0	0.55	0.4
343	0.1	0.10	0.3	4.0	0.55	0.3
344	0.1	0.10	0.2	4.0	0.55	0.1
345	0.15	0.10	0.25	4.0	0.55	0.2
346	0.1	0.10	0.05	4.0	0.55	0.4
351	0	0.10	0.1	4.0	0.55	0
352	0.15	0.10	0.35	4.0	0.55	0.4
353	0.1	0.10	0.3	4.0	0.55	0.3
354	0.1	0.10	0.2	4.0	0.55	0.1
355	0.15	0.10	0.25	4.0	0.55	0.2
356	0.1	0.10	0.05	4.0	0.55	0.4
361	0	0.10	0.1	4.0	0.55	0
362	0.15	0.10	0.35	4.0	0.55	0.4
363	0.1	0.10	0.3	4.0	0.55	0.3
364	0.1	0.10	0.2	4.0	0.55	0.1
365	0.15	0.10	0.25	4.0	0.55	0.2
366	0.1	0.10	0.05	4.0	0.55	0.4
371	0	0.10	0.1	4.0	0.55	0
372	0.15	0.10	0.35	4.0	0.55	0.4
373	0.1	0.10	0.3	4.0	0.55	0.3
374	0.1	0.10	0.2	4.0	0.55	0.1
375	0.15	0.10	0.25	4.0	0.55	0.2

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
376	0.1	0.10	0.05	4.0	0.55	0.4
381	0	0.10	0.1	4.0	0.55	0
382	0.15	0.10	0.35	4.0	0.55	0.4
383	0.1	0.10	0.3	4.0	0.55	0.3
384	0.1	0.10	0.2	4.0	0.55	0.1
385	0.15	0.10	0.25	4.0	0.55	0.2
386	0.1	0.10	0.05	4.0	0.55	0.4
391	0	0.10	0.1	4.0	0.55	0
392	0.15	0.10	0.35	4.0	0.55	0.4
393	0.1	0.10	0.3	4.0	0.55	0.3
394	0.1	0.10	0.2	4.0	0.55	0.1
395	0.15	0.10	0.25	4.0	0.55	0.2
396	0.1	0.10	0.05	4.0	0.55	0.4
401	0	0.10	0.1	4.0	0.55	0
402	0.15	0.10	0.35	4.0	0.55	0.4
403	0.1	0.10	0.3	4.0	0.55	0.3
404	0.1	0.10	0.2	4.0	0.55	0.1
405	0.15	0.10	0.25	4.0	0.55	0.2
411	0	0.10	0.1	4.0	0.55	0
412	0.15	0.10	0.35	4.0	0.55	0.4
413	0.1	0.10	0.3	4.0	0.55	0.3
414	0.1	0.10	0.2	4.0	0.55	0.1
415	0.15	0.10	0.25	4.0	0.55	0.2
416	0.1	0.10	0.05	4.0	0.55	0.4
421	0	0.10	0.1	4.0	0.55	0
422	0.15	0.10	0.35	4.0	0.55	0.4
423	0.1	0.10	0.3	4.0	0.55	0.3
424	0.1	0.10	0.2	4.0	0.55	0.1
425	0.15	0.10	0.25	4.0	0.55	0.2
426	0.1	0.10	0.05	4.0	0.55	0.4
431	0	0.10	0.1	4.0	0.55	0
432	0.15	0.10	0.35	4.0	0.55	0.4
433	0.1	0.10	0.3	4.0	0.55	0.3
434	0.1	0.10	0.2	4.0	0.55	0.1
435	0.15	0.10	0.25	4.0	0.55	0.2
436	0.1	0.10	0.05	4.0	0.55	0.4
441	0	0.10	0.1	4.0	0.55	0
442	0.15	0.10	0.35	4.0	0.55	0.4
443	0.1	0.10	0.3	4.0	0.55	0.3
444	0.1	0.10	0.2	4.0	0.55	0.1
445	0.15	0.10	0.25	4.0	0.55	0.2
446	0.1	0.10	0.05	4.0	0.55	0.4
451	0	0.10	0.1	4.0	0.55	0
452	0.15	0.10	0.35	4.0	0.55	0.4
453	0.1	0.10	0.3	4.0	0.55	0.3
454	0.1	0.10	0.2	4.0	0.55	0.1
455	0.15	0.10	0.25	4.0	0.55	0.2
456	0.1	0.10	0.05	4.0	0.55	0.4
462	0.15	0.10	0.35	4.0	0.55	0.4
463	0.1	0.10	0.3	4.0	0.55	0.3
464	0.1	0.10	0.2	4.0	0.55	0.1
465	0.15	0.10	0.25	4.0	0.55	0.2
471	0	0.10	0.1	4.0	0.55	0
472	0.15	0.10	0.35	4.0	0.55	0.4
473	0.1	0.10	0.3	4.0	0.55	0.3
474	0.1	0.10	0.2	4.0	0.55	0.1
475	0.15	0.10	0.25	4.0	0.55	0.2
476	0.1	0.10	0.05	4.0	0.55	0.4
481	0	0.10	0.1	4.0	0.55	0
482	0.15	0.10	0.35	4.0	0.55	0.4
483	0.1	0.10	0.3	4.0	0.55	0.3
484	0.1	0.10	0.2	4.0	0.55	0.1
485	0.15	0.10	0.25	4.0	0.55	0.2
486	0.1	0.10	0.05	4.0	0.55	0.4
491	0	0.10	0.1	4.0	0.55	0
492	0.15	0.10	0.35	4.0	0.55	0.4

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
493	0.1	0.10	0.3	4.0	0.55	0.3
494	0.1	0.10	0.2	4.0	0.55	0.1
495	0.15	0.10	0.25	4.0	0.55	0.2
496	0.1	0.10	0.05	4.0	0.55	0.4
501	0	0.10	0.1	4.0	0.55	0
502	0.15	0.10	0.35	4.0	0.55	0.4
503	0.1	0.10	0.3	4.0	0.55	0.3
504	0.1	0.10	0.2	4.0	0.55	0.1
505	0.15	0.10	0.25	4.0	0.55	0.2
506	0.1	0.10	0.05	4.0	0.55	0.4
511	0	0.10	0.1	4.0	0.55	0
512	0.15	0.10	0.35	4.0	0.55	0.4
513	0.1	0.10	0.3	4.0	0.55	0.3
514	0.1	0.10	0.2	4.0	0.55	0.1
515	0.15	0.10	0.25	4.0	0.55	0.2
516	0.1	0.10	0.05	4.0	0.55	0.4
521	0	0.10	0.1	4.0	0.55	0
522	0.15	0.10	0.35	4.0	0.55	0.4
523	0.1	0.10	0.3	4.0	0.55	0.3
524	0.1	0.10	0.2	4.0	0.55	0.1
525	0.15	0.10	0.25	4.0	0.55	0.2
526	0.1	0.10	0.05	4.0	0.55	0.4
531	0	0.10	0.1	4.0	0.55	0
532	0.15	0.10	0.35	4.0	0.55	0.4
533	0.1	0.10	0.3	4.0	0.55	0.3
534	0.1	0.10	0.2	4.0	0.55	0.1
535	0.15	0.10	0.25	4.0	0.55	0.2
536	0.1	0.10	0.05	4.0	0.55	0.4
542	0.15	0.10	0.35	4.0	0.55	0.4
543	0.1	0.10	0.3	4.0	0.55	0.3
544	0.1	0.10	0.2	4.0	0.55	0.1
545	0.15	0.10	0.25	4.0	0.55	0.2
546	0.1	0.10	0.05	4.0	0.55	0.4
551	0	0.10	0.1	4.0	0.55	0
552	0.15	0.10	0.35	4.0	0.55	0.4
553	0.1	0.10	0.3	4.0	0.55	0.3
554	0.1	0.10	0.2	4.0	0.55	0.1
555	0.15	0.10	0.25	4.0	0.55	0.2
556	0.1	0.10	0.05	4.0	0.55	0.4
561	0	0.10	0.1	4.0	0.55	0
562	0.15	0.10	0.35	4.0	0.55	0.4
563	0.1	0.10	0.3	4.0	0.55	0.3
564	0.1	0.10	0.2	4.0	0.55	0.1
565	0.15	0.10	0.25	4.0	0.55	0.2
566	0.1	0.10	0.05	4.0	0.55	0.4
572	0.15	0.10	0.35	4.0	0.55	0.4
573	0.1	0.10	0.3	4.0	0.55	0.3
574	0.1	0.10	0.2	4.0	0.55	0.1
575	0.15	0.10	0.25	4.0	0.55	0.2
576	0.1	0.10	0.05	4.0	0.55	0.4
581	0	0.10	0.1	4.0	0.55	0
582	0.15	0.10	0.35	4.0	0.55	0.4
583	0.1	0.10	0.3	4.0	0.55	0.3
584	0.1	0.10	0.2	4.0	0.55	0.1
585	0.15	0.10	0.25	4.0	0.55	0.2
586	0.1	0.10	0.05	4.0	0.55	0.4
591	0	0.10	0.1	4.0	0.55	0
592	0.15	0.10	0.35	4.0	0.55	0.4
593	0.1	0.10	0.3	4.0	0.55	0.3
594	0.1	0.10	0.2	4.0	0.55	0.1
595	0.15	0.10	0.25	4.0	0.55	0.2
596	0.1	0.10	0.05	4.0	0.55	0.4
601	0	0.10	0.1	4.0	0.55	0
602	0.15	0.10	0.35	4.0	0.55	0.4
603	0.1	0.10	0.3	4.0	0.55	0.3
604	0.1	0.10	0.2	4.0	0.55	0.1

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
605	0.15	0.10	0.25	4.0	0.55	0.2
606	0.1	0.10	0.05	4.0	0.55	0.4
611	0	0.10	0.1	4.0	0.55	0
612	0.15	0.10	0.35	4.0	0.55	0.4
613	0.1	0.10	0.3	4.0	0.55	0.3
614	0.1	0.10	0.2	4.0	0.55	0.1
615	0.15	0.10	0.25	4.0	0.55	0.2
616	0.1	0.10	0.05	4.0	0.55	0.4
621	0	0.10	0.1	4.0	0.55	0
622	0.15	0.10	0.35	4.0	0.55	0.4
623	0.1	0.10	0.3	4.0	0.55	0.3
624	0.1	0.10	0.2	4.0	0.55	0.1
625	0.15	0.10	0.25	4.0	0.55	0.2
626	0.1	0.10	0.05	4.0	0.55	0.4

PWater – State Parameter Set

*** < PLS>	PWATER state variables (in)						
*** x - x	CEPS	SURS	UZS	IFWS	LZS	AGWS	GWVS
11 626	0.	0.	0.10	0.	6.2	1.66	0.

LOWER SANDIES

PWater – Parameter Set 2

*** < PLS>		FOREST	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
*** x	- x		(in)	(in/hr)	(ft)		(1/in)	(1/day)
11		0	6.2	0.01	776	0.077	0.	0.999
12	16	0	6.2	0.03	776	0.077	0.	0.999
21		0	6.2	0.01	941	0.066	0.	0.999
22	26	0	6.2	0.03	941	0.066	0.	0.999
32	35	0	6.2	0.03	2816	0.089	0.	0.999
41		0	6.2	0.01	745	0.058	0.	0.999
42	46	0	6.2	0.03	745	0.058	0.	0.999
51		0	6.2	0.01	869	0.047	0.	0.999
52	56	0	6.2	0.03	869	0.047	0.	0.999
61		0	6.2	0.01	727	0.046	0.	0.999
62	66	0	6.2	0.02	727	0.046	0.	0.999
71		0	6.2	0.01	889	0.046	0.	0.999
72	76	0	6.2	0.02	889	0.046	0.	0.999
81		0	6.2	0.01	887	0.05	0.	0.999
82	86	0	6.2	0.03	887	0.05	0.	0.999
91		0	6.2	0.01	1002	0.051	0.	0.999
92	95	0	6.2	0.03	1002	0.051	0.	0.999
102	106	0	6.2	0.03	902	0.053	0.	0.999
111		0	6.2	0.01	1040	0.055	0.	0.999
112	116	0	6.2	0.03	1040	0.055	0.	0.999
122	126	0	6.2	0.03	926	0.07	0.	0.999
131		0	6.2	0.01	878	0.044	0.	0.999
132	136	0	6.2	0.02	878	0.044	0.	0.999
141	146	0	6.2	0.01	889	0.03	0.	0.999
151	156	0	6.2	0.01	822	0.046	0.	0.999
161		0	6.2	0.01	1320	0.04	0.	0.999
162	166	0	6.2	0.02	1320	0.04	0.	0.999
171		0	6.2	0.01	869	0.035	0.	0.999
172	176	0	6.2	0.03	869	0.035	0.	0.999
181		0	6.2	0.01	1074	0.031	0.	0.999
182	186	0	6.2	0.03	1074	0.031	0.	0.999
191	196	0	6.2	0.01	831	0.036	0.	0.999
201		0	6.2	0.01	859	0.036	0.	0.999
202	206	0	6.2	0.02	859	0.036	0.	0.999
211	216	0	6.2	0.01	728	0.051	0.	0.999
221		0	6.2	0.01	804	0.039	0.	0.999
222	226	0	6.2	0.02	804	0.039	0.	0.999
231		0	6.2	0.01	976	0.046	0.	0.999
232	236	0	6.2	0.03	976	0.046	0.	0.999
242	246	0	6.2	0.03	714	0.036	0.	0.999
251	256	0	6.2	0.01	988	0.05	0.	0.999
261	266	0	6.2	0.01	915	0.042	0.	0.999
271	276	0	6.2	0.01	875	0.032	0.	0.999
282	286	0	6.2	0.02	1276	0.059	0.	0.999
292	295	0	6.2	0.02	1590	0.041	0.	0.999
301	306	0	6.2	0.01	900	0.033	0.	0.999
311	315	0	6.2	0.01	1017	0.039	0.	0.999
321	326	0	6.2	0.01	808	0.041	0.	0.999
331		0	6.2	0.01	1161	0.03	0.	0.999
332	336	0	6.2	0.02	1161	0.03	0.	0.999
341		0	6.2	0.01	1104	0.036	0.	0.999
342	346	0	6.2	0.03	1104	0.036	0.	0.999
351		0	6.2	0.01	828	0.048	0.	0.999
352	356	0	6.2	0.02	828	0.048	0.	0.999
361		0	6.2	0.01	1002	0.04	0.	0.999
362	366	0	6.2	0.03	1002	0.04	0.	0.999
371		0	6.2	0.01	1513	0.075	0.	0.999
372	376	0	6.2	0.02	1513	0.075	0.	0.999

*** <	PLS>	FOREST	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
*** x	- x		(in)	(in/hr)	(ft)		(1/in)	(1/day)
381		0	6.2	0.01	1071	0.04	0.	0.999
382	386	0	6.2	0.02	1071	0.04	0.	0.999
391		0	6.2	0.01	953	0.047	0.	0.999
392	396	0	6.2	0.03	953	0.047	0.	0.999
401		0	6.2	0.01	950	0.044	0.	0.999
402	406	0	6.2	0.03	950	0.044	0.	0.999
412	416	0	6.2	0.03	999	0.054	0.	0.999
421		0	6.2	0.01	995	0.051	0.	0.999
422	426	0	6.2	0.03	995	0.051	0.	0.999
431		0	6.2	0.01	993	0.052	0.	0.999
432	436	0	6.2	0.03	993	0.052	0.	0.999
441		0	6.2	0.01	845	0.038	0.	0.999
442	446	0	6.2	0.03	845	0.038	0.	0.999
451		0	6.2	0.01	677	0.042	0.	0.999
452	456	0	6.2	0.03	677	0.042	0.	0.999

PWater – Parameter Set 3

*** <	PLS>	PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
*** x	- x	(deg F)	(deg F)					
11	15	0.	0.	2.	2.	0.	0.	0.
16		0.	0.	2.	2.	0.	0.	0.05
21	25	0.	0.	2.	2.	0.	0.	0.
26		0.	0.	2.	2.	0.	0.	0.05
32	45	0.	0.	2.	2.	0.	0.	0.
46		0.	0.	2.	2.	0.	0.	0.05
51	55	0.	0.	2.	2.	0.	0.	0.
56		0.	0.	2.	2.	0.	0.	0.05
61	65	0.	0.	2.	2.	0.	0.	0.
66		0.	0.	2.	2.	0.	0.	0.05
71	75	0.	0.	2.	2.	0.	0.	0.
76		0.	0.	2.	2.	0.	0.	0.05
81	85	0.	0.	2.	2.	0.	0.	0.
86		0.	0.	2.	2.	0.	0.	0.05
91	105	0.	0.	2.	2.	0.	0.	0.
106		0.	0.	2.	2.	0.	0.	0.05
111	115	0.	0.	2.	2.	0.	0.	0.
116		0.	0.	2.	2.	0.	0.	0.05
122	125	0.	0.	2.	2.	0.	0.	0.
126		0.	0.	2.	2.	0.	0.	0.05
131	135	0.	0.	2.	2.	0.	0.	0.
136		0.	0.	2.	2.	0.	0.	0.05
141	145	0.	0.	2.	2.	0.	0.	0.
146		0.	0.	2.	2.	0.	0.	0.05
151	155	0.	0.	2.	2.	0.	0.	0.
156		0.	0.	2.	2.	0.	0.	0.05
161	165	0.	0.	2.	2.	0.	0.	0.
166		0.	0.	2.	2.	0.	0.	0.05
171	175	0.	0.	2.	2.	0.	0.	0.
176		0.	0.	2.	2.	0.	0.	0.05
181	185	0.	0.	2.	2.	0.	0.	0.
186		0.	0.	2.	2.	0.	0.	0.05
191	195	0.	0.	2.	2.	0.	0.	0.
196		0.	0.	2.	2.	0.	0.	0.05
201	205	0.	0.	2.	2.	0.	0.	0.
206		0.	0.	2.	2.	0.	0.	0.05
211	215	0.	0.	2.	2.	0.	0.	0.
216		0.	0.	2.	2.	0.	0.	0.05
221	225	0.	0.	2.	2.	0.	0.	0.
226		0.	0.	2.	2.	0.	0.	0.05
231	235	0.	0.	2.	2.	0.	0.	0.
236		0.	0.	2.	2.	0.	0.	0.05
242	245	0.	0.	2.	2.	0.	0.	0.

*** < PLS>		PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
*** x	- x	(deg F)	(deg F)					
246		0.	0.	2.	2.	0.	0.	0.05
251	255	0.	0.	2.	2.	0.	0.	0.
256		0.	0.	2.	2.	0.	0.	0.05
261	265	0.	0.	2.	2.	0.	0.	0.
266		0.	0.	2.	2.	0.	0.	0.05
271	275	0.	0.	2.	2.	0.	0.	0.
276		0.	0.	2.	2.	0.	0.	0.05
282	285	0.	0.	2.	2.	0.	0.	0.
286		0.	0.	2.	2.	0.	0.	0.05
292	305	0.	0.	2.	2.	0.	0.	0.
306		0.	0.	2.	2.	0.	0.	0.05
311	325	0.	0.	2.	2.	0.	0.	0.
326		0.	0.	2.	2.	0.	0.	0.05
331	335	0.	0.	2.	2.	0.	0.	0.
336		0.	0.	2.	2.	0.	0.	0.05
341	345	0.	0.	2.	2.	0.	0.	0.
346		0.	0.	2.	2.	0.	0.	0.05
351	355	0.	0.	2.	2.	0.	0.	0.
356		0.	0.	2.	2.	0.	0.	0.05
361	365	0.	0.	2.	2.	0.	0.	0.
366		0.	0.	2.	2.	0.	0.	0.05
371	375	0.	0.	2.	2.	0.	0.	0.
376		0.	0.	2.	2.	0.	0.	0.05
381	385	0.	0.	2.	2.	0.	0.	0.
386		0.	0.	2.	2.	0.	0.	0.05
391	395	0.	0.	2.	2.	0.	0.	0.
396		0.	0.	2.	2.	0.	0.	0.05
401	405	0.	0.	2.	2.	0.	0.	0.
406		0.	0.	2.	2.	0.	0.	0.05
412	415	0.	0.	2.	2.	0.	0.	0.
416		0.	0.	2.	2.	0.	0.	0.05
421	425	0.	0.	2.	2.	0.	0.	0.
426		0.	0.	2.	2.	0.	0.	0.05
431	435	0.	0.	2.	2.	0.	0.	0.
436		0.	0.	2.	2.	0.	0.	0.05
441	445	0.	0.	2.	2.	0.	0.	0.
446		0.	0.	2.	2.	0.	0.	0.05
451	455	0.	0.	2.	2.	0.	0.	0.
456		0.	0.	2.	2.	0.	0.	0.05

PWater – Parameter Set 4

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
11	0.	0.10	0.1	4.0	0.55	0.
12	0.15	0.10	0.35	4.0	0.55	0.4
13	0.1	0.10	0.3	4.0	0.55	0.3
14	0.1	0.10	0.2	4.0	0.55	0.1
15	0.15	0.10	0.25	4.0	0.55	0.2
16	0.1	0.10	0.05	4.0	0.55	0.4
21	0.	0.10	0.1	4.0	0.55	0.
22	0.15	0.10	0.35	4.0	0.55	0.4
23	0.1	0.10	0.3	4.0	0.55	0.3
24	0.1	0.10	0.2	4.0	0.55	0.1
25	0.15	0.10	0.25	4.0	0.55	0.2
26	0.1	0.10	0.05	4.0	0.55	0.4
32	0.15	0.10	0.35	4.0	0.55	0.4
33	0.1	0.10	0.3	4.0	0.55	0.3
34	0.1	0.10	0.2	4.0	0.55	0.1
35	0.15	0.10	0.25	4.0	0.55	0.2
41	0.	0.10	0.1	4.0	0.55	0.
42	0.15	0.10	0.35	4.0	0.55	0.4
43	0.1	0.10	0.3	4.0	0.55	0.3

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
44	0.1	0.10	0.2	4.0	0.55	0.1
45	0.15	0.10	0.25	4.0	0.55	0.2
46	0.1	0.10	0.05	4.0	0.55	0.4
51	0.	0.10	0.1	4.0	0.55	0.
52	0.15	0.10	0.35	4.0	0.55	0.4
53	0.1	0.10	0.3	4.0	0.55	0.3
54	0.1	0.10	0.2	4.0	0.55	0.1
55	0.15	0.10	0.25	4.0	0.55	0.2
56	0.1	0.10	0.05	4.0	0.55	0.4
61	0.	0.10	0.1	4.0	0.55	0.
62	0.15	0.10	0.35	4.0	0.55	0.4
63	0.1	0.10	0.3	4.0	0.55	0.3
64	0.1	0.10	0.2	4.0	0.55	0.1
65	0.15	0.10	0.25	4.0	0.55	0.2
66	0.1	0.10	0.05	4.0	0.55	0.4
71	0.	0.10	0.1	4.0	0.55	0.
72	0.15	0.10	0.35	4.0	0.55	0.4
73	0.1	0.10	0.3	4.0	0.55	0.3
74	0.1	0.10	0.2	4.0	0.55	0.1
75	0.15	0.10	0.25	4.0	0.55	0.2
76	0.1	0.10	0.05	4.0	0.55	0.4
81	0.	0.10	0.1	4.0	0.55	0.
82	0.15	0.10	0.35	4.0	0.55	0.4
83	0.1	0.10	0.3	4.0	0.55	0.3
84	0.1	0.10	0.2	4.0	0.55	0.1
85	0.15	0.10	0.25	4.0	0.55	0.2
86	0.1	0.10	0.05	4.0	0.55	0.4
91	0.	0.10	0.1	4.0	0.55	0.
92	0.15	0.10	0.35	4.0	0.55	0.4
93	0.1	0.10	0.3	4.0	0.55	0.3
94	0.1	0.10	0.2	4.0	0.55	0.1
95	0.15	0.10	0.25	4.0	0.55	0.2
102	0.15	0.10	0.35	4.0	0.55	0.4
103	0.1	0.10	0.3	4.0	0.55	0.3
104	0.1	0.10	0.2	4.0	0.55	0.1
105	0.15	0.10	0.25	4.0	0.55	0.2
106	0.1	0.10	0.05	4.0	0.55	0.4
111	0.	0.10	0.1	4.0	0.55	0.
112	0.15	0.10	0.35	4.0	0.55	0.4
113	0.1	0.10	0.3	4.0	0.55	0.3
114	0.1	0.10	0.2	4.0	0.55	0.1
115	0.15	0.10	0.25	4.0	0.55	0.2
116	0.1	0.10	0.05	4.0	0.55	0.4
122	0.15	0.10	0.35	4.0	0.55	0.4
123	0.1	0.10	0.3	4.0	0.55	0.3
124	0.1	0.10	0.2	4.0	0.55	0.1
125	0.15	0.10	0.25	4.0	0.55	0.2
126	0.1	0.10	0.05	4.0	0.55	0.4
131	0.	0.10	0.1	4.0	0.55	0.
132	0.15	0.10	0.35	4.0	0.55	0.4
133	0.1	0.10	0.3	4.0	0.55	0.3
134	0.1	0.10	0.2	4.0	0.55	0.1
135	0.15	0.10	0.25	4.0	0.55	0.2
136	0.1	0.10	0.05	4.0	0.55	0.4
141	0.	0.10	0.1	4.0	0.55	0.
142	0.15	0.10	0.35	4.0	0.55	0.4
143	0.1	0.10	0.3	4.0	0.55	0.3
144	0.1	0.10	0.2	4.0	0.55	0.1
145	0.15	0.10	0.25	4.0	0.55	0.2
146	0.1	0.10	0.05	4.0	0.55	0.4
151	0.	0.10	0.1	4.0	0.55	0.
152	0.15	0.10	0.35	4.0	0.55	0.4
153	0.1	0.10	0.3	4.0	0.55	0.3
154	0.1	0.10	0.2	4.0	0.55	0.1
155	0.15	0.10	0.25	4.0	0.55	0.2
156	0.1	0.10	0.05	4.0	0.55	0.4

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
161	0.	0.10	0.1	4.0	0.55	0.
162	0.15	0.10	0.35	4.0	0.55	0.4
163	0.1	0.10	0.3	4.0	0.55	0.3
164	0.1	0.10	0.2	4.0	0.55	0.1
165	0.15	0.10	0.25	4.0	0.55	0.2
166	0.1	0.10	0.05	4.0	0.55	0.4
171	0.	0.10	0.1	4.0	0.55	0.
172	0.15	0.10	0.35	4.0	0.55	0.4
173	0.1	0.10	0.3	4.0	0.55	0.3
174	0.1	0.10	0.2	4.0	0.55	0.1
175	0.15	0.10	0.25	4.0	0.55	0.2
176	0.1	0.10	0.05	4.0	0.55	0.4
181	0.	0.10	0.1	4.0	0.55	0.
182	0.15	0.10	0.35	4.0	0.55	0.4
183	0.1	0.10	0.3	4.0	0.55	0.3
184	0.1	0.10	0.2	4.0	0.55	0.1
185	0.15	0.10	0.25	4.0	0.55	0.2
186	0.1	0.10	0.05	4.0	0.55	0.4
191	0.	0.10	0.1	4.0	0.55	0.
192	0.15	0.10	0.35	4.0	0.55	0.4
193	0.1	0.10	0.3	4.0	0.55	0.3
194	0.1	0.10	0.2	4.0	0.55	0.1
195	0.15	0.10	0.25	4.0	0.55	0.2
196	0.1	0.10	0.05	4.0	0.55	0.4
201	0.	0.10	0.1	4.0	0.55	0.
202	0.15	0.10	0.35	4.0	0.55	0.4
203	0.1	0.10	0.3	4.0	0.55	0.3
204	0.1	0.10	0.2	4.0	0.55	0.1
205	0.15	0.10	0.25	4.0	0.55	0.2
206	0.1	0.10	0.05	4.0	0.55	0.4
211	0.	0.10	0.1	4.0	0.55	0.
212	0.15	0.10	0.35	4.0	0.55	0.4
213	0.1	0.10	0.3	4.0	0.55	0.3
214	0.1	0.10	0.2	4.0	0.55	0.1
215	0.15	0.10	0.25	4.0	0.55	0.2
216	0.1	0.10	0.05	4.0	0.55	0.4
221	0.	0.10	0.1	4.0	0.55	0.
222	0.15	0.10	0.35	4.0	0.55	0.4
223	0.1	0.10	0.3	4.0	0.55	0.3
224	0.1	0.10	0.2	4.0	0.55	0.1
225	0.15	0.10	0.25	4.0	0.55	0.2
226	0.1	0.10	0.05	4.0	0.55	0.4
231	0.	0.10	0.1	4.0	0.55	0.
232	0.15	0.10	0.35	4.0	0.55	0.4
233	0.1	0.10	0.3	4.0	0.55	0.3
234	0.1	0.10	0.2	4.0	0.55	0.1
235	0.15	0.10	0.25	4.0	0.55	0.2
236	0.1	0.10	0.05	4.0	0.55	0.4
242	0.15	0.10	0.35	4.0	0.55	0.4
243	0.1	0.10	0.3	4.0	0.55	0.3
244	0.1	0.10	0.2	4.0	0.55	0.1
245	0.15	0.10	0.25	4.0	0.55	0.2
246	0.1	0.10	0.05	4.0	0.55	0.4
251	0.	0.10	0.1	4.0	0.55	0.
252	0.15	0.10	0.35	4.0	0.55	0.4
253	0.1	0.10	0.3	4.0	0.55	0.3
254	0.1	0.10	0.2	4.0	0.55	0.1
255	0.15	0.10	0.25	4.0	0.55	0.2
256	0.1	0.10	0.05	4.0	0.55	0.4
261	0.	0.10	0.1	4.0	0.55	0.
262	0.15	0.10	0.35	4.0	0.55	0.4
263	0.1	0.10	0.3	4.0	0.55	0.3
264	0.1	0.10	0.2	4.0	0.55	0.1
265	0.15	0.10	0.25	4.0	0.55	0.2
266	0.1	0.10	0.05	4.0	0.55	0.4
271	0.	0.10	0.1	4.0	0.55	0.

*** <PLS >	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
*** x - x	(in)	(in)			(1/day)	
272	0.15	0.10	0.35	4.0	0.55	0.4
273	0.1	0.10	0.3	4.0	0.55	0.3
274	0.1	0.10	0.2	4.0	0.55	0.1
275	0.15	0.10	0.25	4.0	0.55	0.2
276	0.1	0.10	0.05	4.0	0.55	0.4
282	0.15	0.10	0.35	4.0	0.55	0.4
283	0.1	0.10	0.3	4.0	0.55	0.3
284	0.1	0.10	0.2	4.0	0.55	0.1
285	0.15	0.10	0.25	4.0	0.55	0.2
286	0.1	0.10	0.05	4.0	0.55	0.4
292	0.15	0.10	0.35	4.0	0.55	0.4
293	0.1	0.10	0.3	4.0	0.55	0.3
294	0.1	0.10	0.2	4.0	0.55	0.1
295	0.15	0.10	0.25	4.0	0.55	0.2
301	0.	0.10	0.1	4.0	0.55	0.
302	0.15	0.10	0.35	4.0	0.55	0.4
303	0.1	0.10	0.3	4.0	0.55	0.3
304	0.1	0.10	0.2	4.0	0.55	0.1
305	0.15	0.10	0.25	4.0	0.55	0.2
306	0.1	0.10	0.05	4.0	0.55	0.4
311	0.	0.10	0.1	4.0	0.55	0.
312	0.15	0.10	0.35	4.0	0.55	0.4
313	0.1	0.10	0.3	4.0	0.55	0.3
314	0.1	0.10	0.2	4.0	0.55	0.1
315	0.15	0.10	0.25	4.0	0.55	0.2
321	0.	0.10	0.1	4.0	0.55	0.
322	0.15	0.10	0.35	4.0	0.55	0.4
323	0.1	0.10	0.3	4.0	0.55	0.3
324	0.1	0.10	0.2	4.0	0.55	0.1
325	0.15	0.10	0.25	4.0	0.55	0.2
326	0.1	0.10	0.05	4.0	0.55	0.4
331	0.	0.10	0.1	4.0	0.55	0.
332	0.15	0.10	0.35	4.0	0.55	0.4
333	0.1	0.10	0.3	4.0	0.55	0.3
334	0.1	0.10	0.2	4.0	0.55	0.1
335	0.15	0.10	0.25	4.0	0.55	0.2
336	0.1	0.10	0.05	4.0	0.55	0.4
341	0.	0.10	0.1	4.0	0.55	0.
342	0.15	0.10	0.35	4.0	0.55	0.4
343	0.1	0.10	0.3	4.0	0.55	0.3
344	0.1	0.10	0.2	4.0	0.55	0.1
345	0.15	0.10	0.25	4.0	0.55	0.2
346	0.1	0.10	0.05	4.0	0.55	0.4
351	0.	0.10	0.1	4.0	0.55	0.
352	0.15	0.10	0.35	4.0	0.55	0.4
353	0.1	0.10	0.3	4.0	0.55	0.3
354	0.1	0.10	0.2	4.0	0.55	0.1
355	0.15	0.10	0.25	4.0	0.55	0.2
356	0.1	0.10	0.05	4.0	0.55	0.4
361	0.	0.10	0.1	4.0	0.55	0.
362	0.15	0.10	0.35	4.0	0.55	0.4
363	0.1	0.10	0.3	4.0	0.55	0.3
364	0.1	0.10	0.2	4.0	0.55	0.1
365	0.15	0.10	0.25	4.0	0.55	0.2
366	0.1	0.10	0.05	4.0	0.55	0.4
371	0.	0.10	0.1	4.0	0.55	0.
372	0.15	0.10	0.35	4.0	0.55	0.4
373	0.1	0.10	0.3	4.0	0.55	0.3
374	0.1	0.10	0.2	4.0	0.55	0.1
375	0.15	0.10	0.25	4.0	0.55	0.2
376	0.1	0.10	0.05	4.0	0.55	0.4
381	0.	0.10	0.1	4.0	0.55	0.
382	0.15	0.10	0.35	4.0	0.55	0.4
383	0.1	0.10	0.3	4.0	0.55	0.3
384	0.1	0.10	0.2	4.0	0.55	0.1
385	0.15	0.10	0.25	4.0	0.55	0.2

```
*** <PLS >      CEPSC      UZSN       NSUR      INTFW        IRC      LZETP
*** x -  x      (in)       (in)                             (1/day)
  386            0.1       0.10       0.05        4.0       0.55        0.4
  391            0.        0.10        0.1        4.0       0.55        0.
  392           0.15       0.10       0.35        4.0       0.55        0.4
  393            0.1       0.10        0.3        4.0       0.55        0.3
  394            0.1       0.10        0.2        4.0       0.55        0.1
  395           0.15       0.10       0.25        4.0       0.55        0.2
  396            0.1       0.10       0.05        4.0       0.55        0.4
  401            0.        0.10        0.1        4.0       0.55        0.
  402           0.15       0.10       0.35        4.0       0.55        0.4
  403            0.1       0.10        0.3        4.0       0.55        0.3
  404            0.1       0.10        0.2        4.0       0.55        0.1
  405           0.15       0.10       0.25        4.0       0.55        0.2
  406            0.1       0.10       0.05        4.0       0.55        0.4
  412           0.15       0.10       0.35        4.0       0.55        0.4
  413            0.1       0.10        0.3        4.0       0.55        0.3
  414            0.1       0.10        0.2        4.0       0.55        0.1
  415           0.15       0.10       0.25        4.0       0.55        0.2
  416            0.1       0.10       0.05        4.0       0.55        0.4
  421            0.        0.10        0.1        4.0       0.55        0.
  422           0.15       0.10       0.35        4.0       0.55        0.4
  423            0.1       0.10        0.3        4.0       0.55        0.3
  424            0.1       0.10        0.2        4.0       0.55        0.1
  425           0.15       0.10       0.25        4.0       0.55        0.2
  426            0.1       0.10       0.05        4.0       0.55        0.4
  431            0.        0.10        0.1        4.0       0.55        0.
  432           0.15       0.10       0.35        4.0       0.55        0.4
  433            0.1       0.10        0.3        4.0       0.55        0.3
  434            0.1       0.10        0.2        4.0       0.55        0.1
  435           0.15       0.10       0.25        4.0       0.55        0.2
  436            0.1       0.10       0.05        4.0       0.55        0.4
  441            0.        0.10        0.1        4.0       0.55        0.
  442           0.15       0.10       0.35        4.0       0.55        0.4
  443            0.1       0.10        0.3        4.0       0.55        0.3
  444            0.1       0.10        0.2        4.0       0.55        0.1
  445           0.15       0.10       0.25        4.0       0.55        0.2
  446            0.1       0.10       0.05        4.0       0.55        0.4
  451            0.        0.10        0.1        4.0       0.55        0.
  452           0.15       0.10       0.35        4.0       0.55        0.4
  453            0.1       0.10        0.3        4.0       0.55        0.3
  454            0.1       0.10        0.2        4.0       0.55        0.1
  455           0.15       0.10       0.25        4.0       0.55        0.2
  456            0.1       0.10       0.05        4.0       0.55        0.4
```

PWater – Parameter Set 4

```
*** < PLS>  PWATER state variables (in)
*** x  - x       CEPS       SURS        UZS       IFWS        LZS       AGWS       GWVS
   11  456         0.         0.       0.10         0.        6.2       1.66         0.
```

Abbreviations

AGWRC	Active Groundwater Evapotranspiration
ARM	Agricultural Runoff Management model
BASETP	Base Evapotranspiration
BASINS	Better Assessment Science Integrating point and Nonpoint Sources
CEPSC	Rainfall Vegetation Interception
CFS	Cubic Feet per Second
CRP	Clean Rivers Program
CWA	Clean Water Act
DAYMET	DAilY METeorological
DEEPFR	Deep Recharge Fraction
DOD	Department Of Defense
ECTF	East Central Texas Forests
EPA	Environmental Protection Agency
FTABLE	Function TABLE
GBRA	Guadalupe-Blanco River Authority
GenScn	Scenario Generator
HRAP	Hydrologic Rainfall Analysis Project
HSP	HydroComp Simulation Program
HSPF	Hydrologic Simulation Program - FORTRAN
IDW	Inverse Distance Weighted
IMPLND	Impervious Land Segment
INFEXP	Infiltration Exponent
INFILD	Infiltration max to mean ratio

INFILT	Index to Mean Soil Infiltration Rate
IRC	Interflow Recession Parameter
KVARY	Variable Groundwater Recession
LSUR	Length of Overland Flow Plane
LZETP	Lower Zone Evapotranspiration
LZSN	Lower Zone Numerical Soil Moisture Storage
MGD	Million Gallons per Day
NAD27	North American Datum 1927
NAD83	North American Datum 1983
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center
NCEP	National Center for Environmental Prediction
NED	National Elevation Dataset
NEXRAD	Next Generation RADAR
NGVD29	National Geodetic Vertical Datum 1929
NHD	National Hydrography Dataset
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPS	Nonpoint Source Pollutant loading model
NSUR	Manning's n for Overland Flow Plane
NTSG	Numerical Terradynamic Simulation Group
NWIS	National Water Information System
NWS	National Weather Service
PERLND	Pervious Land Segment
RCHRES	Reach

SLSUR	Slope of Overland Flow Path
SSURGO	Soil Survey Geographic
STATSGO	State Soil Geographic
TCEQ	Texas Commission for Environmental Quality
TMDL	Total Mass Daily Load
uci	User Control Input
UGRA	Upper Guadalupe River Authority
USGS	United States Geological Survey
UZSN	Nominal Upper Zone Soil Moisture Storage
WGRFC	West Gulf River Forecast Center

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